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March 2017

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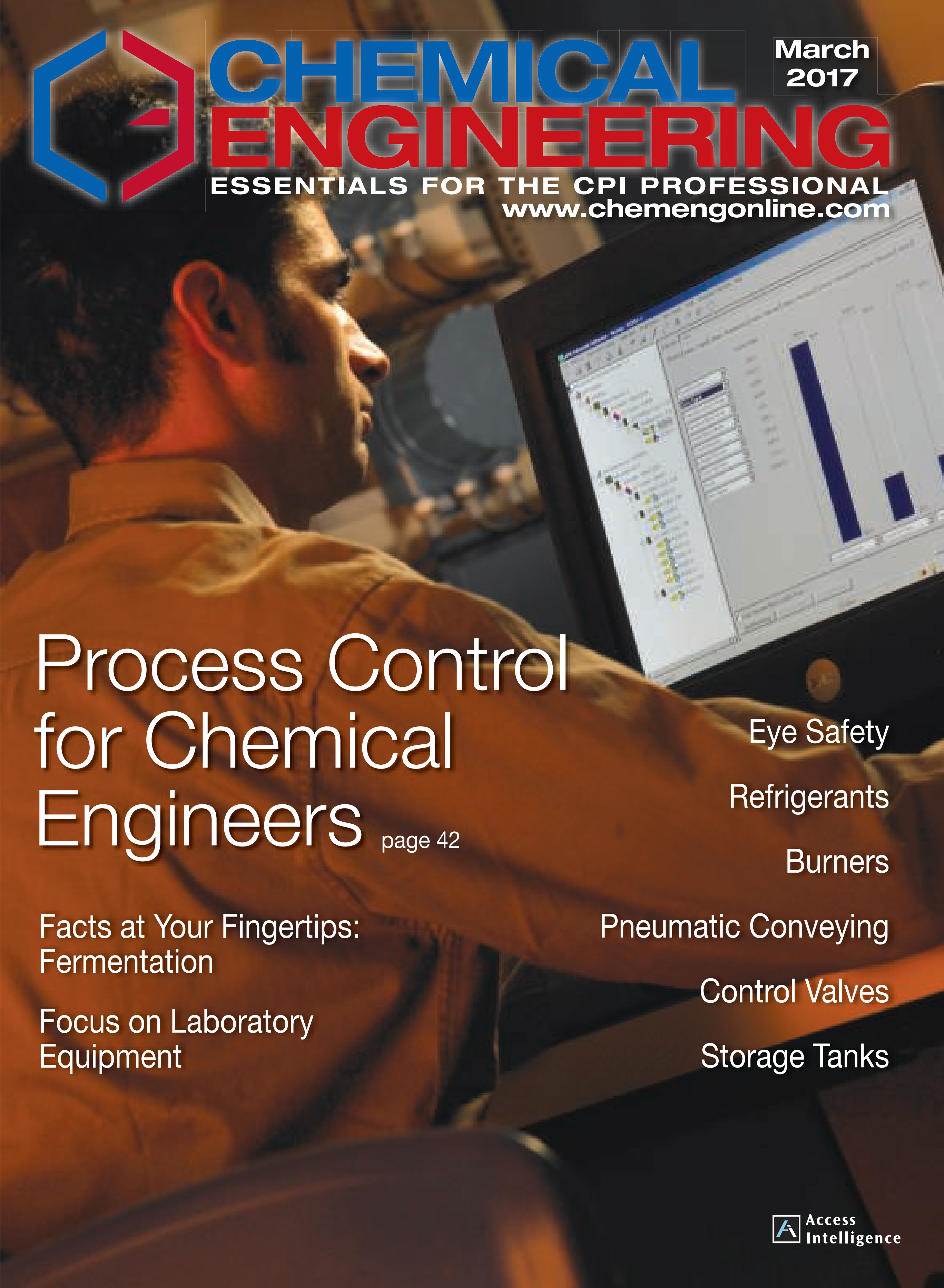

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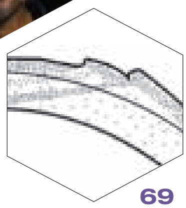

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ESSENTIALS FOR THE CPI PROFESSIONAL

Editor's Page

Going digital

In these times of fast-changing automation, more and more companies are talking about "going digital." Converting to digital data is not new, but thanks to new, enabling technologies, today's digital culture has evolved into something far beyond what could have been imagined not too many years ago. "Going digital" is no longer just a reference to switching from analog to digital technology or going paperless in the office. And, it can mean different things to different companies, depending on where they are in the digital transition. At the recent ARC Forum, "Industry in Transition: Realizing the Digital Enterprise" (February 6–9, Orlando, Fla.), one definition, given by Marty Edwards from the U.S. Dept. of Homeland Security (DHS) in his keynote address, is that digital means "connected." While being connected is certainly at the core of digitalization, the transition seems to mean something much more holistic to most, and encompasses the Industrial Internet of Things, big data, smart machines, cloud computing, streaming analytics, augmented reality and more.

Applications in the CPI

Digitalization brings a host of possibilities to the industrial community. One concept offered by several companies is that of "digital twins," where simulation software and actual data can be used to create a digital shadow, or virtual twin, of a running process. The "twin" can be used in various ways, for example to optimize a process or for predictive maintenance.

Another exciting area with applications in industry is augmented reality. Photos, videos and more can be used to create a three-dimensional reconstruction of a physical plant. This reconstruction can then be used for a variety of applications, such as for planning maintenance changes and for training purposes.

Data analytics, such as realtime analyses of incoming data, also called streaming analytics, is another benefit of digitalization.

In addition to offering data about production and operability, digitalization can be used in business models by tying the business side to production. Within the chemical process industries (CPI), one example of the move toward digitalization is a recent announcement by Evonik Industries (Essen, Germany). The company has formed a new subsidiary called Evonik Digital GmbH to be headed by a chief digital officer (CDO). In Evonik's press release, Christian Kullmann, deputy chairman of the Executive Board is quoted as saying, "Digitalization offers more than new technologies. It also creates new opportunities for collaboration and production, and gives rise to new business models and marketing options."

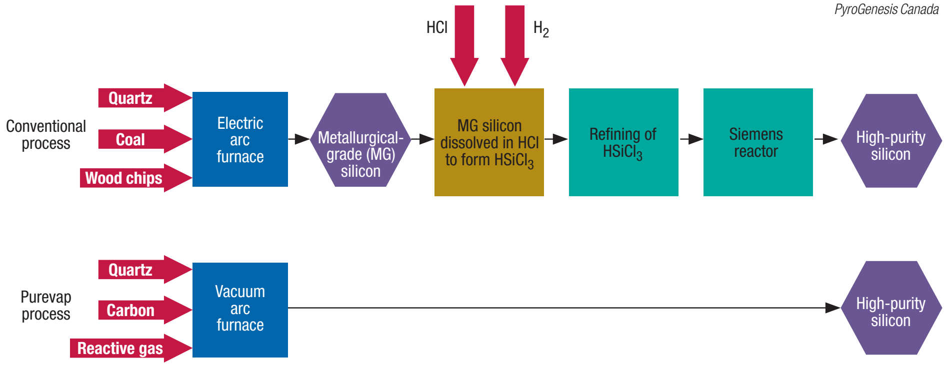
Sound engineering

With all of the excitement around going digital, one has to keep in mind the increasing importance of cybersecurity. At the ARC Forum, DHS's Edwards suggested that depending on your specific process, it may make sense to keep some functions away from being digitized, such as a shut-down function. He suggested that one "big red button" in the facility may need to be kept "unplugged" for human engineering to decide when to push it.

Sound engineering principles are, and will remain a fundamental need in all CPI facilities regardless of how far along they are on the road to digitalization. ■

Dorothy Lozowski, Editorial Director

Single-step production of high-purity silicon demonstrated



Achieving silicon of acceptable purity for solar-energy applications typically requires several purification steps. Now, a new process has been demonstrated that can produce high-purity Si from low-quality quartz in a single step. The PureVap technology from PyroGenesis Canada Inc. (Montreal, Que.; www.pyrogenesis.com) utilizes a powerful vacuum-arc furnace, combining the carbothermic reduction of silicon and purification into one process, explains Pierre Carabin, chief technology officer for PyroGenesis Canada.

Traditional arc furnaces produce relatively low-purity Si, around 98.5% purity, requiring subsequent purification. Inside the PureVap furnace, low-quality (97.5%) quartz and a carbon source are exposed to heat from a plasma arc, creating CO_2 and Si. The vacuum-arc furnace allows for the vaporization of contaminants, including boron and sulfur. By manipulating the metallic vapors' partial pressures, the contaminants are removed.

In 2016, following successful demonstration of the PureVap process at the laboratory scale, PyroGenesis announced a contract worth over $6 million with Canadian mining company HPQ Silicon Resources, Inc. to develop a pilot plant to produce 200 metric tons per year of high-purity Si. The company expects the plant to start up in late 2017.

In January 2017, PyroGenesis announced a series of successful trials, demonstrating both the scalability and repeatability of the PureVap system, as the company begins scaling up production from grams to kilograms. "We have proven that we can remove the contaminants and make significant quantities of silicon. We've also proven that we can consistently produce 99.9% purity silicon. We have been able to produce, on occasion, 99.99% purity," says Carabin. He goes on to say that the company's current objective is to increase this purity to at least 99.999%. According to Carabin, this is the only process in the world to convert low-quality quartz into Si of higher than 99.9% purity. "As far as we know, no one else is doing purification directly from the quartz itself."

Making bio-ethanol from cassava pulp

Sapporo Holdings Ltd. (SHL; Tokyo, Japan; www.sapporoholdings.jp) and Innotech Green Energy Company Ltd. (IGE) in Thailand are collaborating on a project to achieve the world's first practical fermentation process to make ethanol from cassava pulp.

The two companies have completed studies on an 80,000-L/yr pilot demonstration plant, which was part of a project funded by the New Energy and Industrial Technology Development Org. (NEDO, Kawasaki City, Japan; www.nedo.go.jp) that began in 2014. The next step will be the design and construction of a plant with a capacity of 60 million L/yr of ethanol. IGE has begun a feasibility study, based on the results of the pilot project.

Cassava pulp is a waste product generated during the extraction of starch from cassava in the production of tapioca. In Thailand, it is estimated that 2 million tons of cassava pulp waste were generated in 2012, which corresponds to 656 million L of bio-ethanol if the new technology is used. Because of its high fiber content, it has not been possible to utilize cassava pulp as a raw material. A new heat-tolerant yeast, developed by SHL and Iwata Chemical Co., Ltd., makes it feasible to ferment the pulp (for more details, see *Chem. Eng.*, June 2014, p. 12).

Edited by:
Gerald Ondrey

DENOX CATALYSTS

Last month, Haldor Topsøe A/S (Lyngby, Denmark; www.topsoe.com) announced its participation in ProNOx, a new four-year, $4-million research program to improve selective catalytic reduction (SCR) catalysts. Together with two research teams from the Dept. of Chemistry and the Interdisciplinary Nanoscience Center at Aarhus University (Denmark; www.au.dk), Topsøe aims to optimize titanium dioxide nanoparticles to improve the efficiency of catalysts used for cleaning off-gases from engines, industry and power plants.

Currently, the most effective catalyst for removing oxides of nitrogen (NOx) consists of TiO_2 crystals covered with highly dispersed vanadium oxides. ProNOx researchers aim to identify an industrially viable nano-design of the vanadium-covered titanium oxides that will improve the catalyst's performance by 30%.

The program will utilize the most recent research on how to control materials synthesis at the atomic scale by closely integrating synthesis, characterization, modeling and tests. The end-goal is to identify the optimal SCR catalysts and how to produce them in a controlled way.

Approximately $2.8 million in funding for ProNOx is provided by Innovation Fund Denmark (Copenhagen; www.innovationsfonden.dk).

NEW MATERIAL

A team of researchers, led by scientists at the University of California at Riverside (www.ucr.edu) and the University of Colorado at Boulder (www.colorado.edu), has developed the first self-healing, mechanically stretchable, conductive material for possible applications in batteries, electronic devices,

(Continues on p. 8)

robotics and artificial muscles.

The transparent material is a custom-made polymer that uses ion-dipole interactions to promote crosslinking of the polymer chains, the researchers say. Details of the material were recently published in the journal *Advanced Materials*. Researchers say it is the first time anyone has managed to incorporate these diverse properties in a single material. The material's self-healing ability and conductivity could be used to extend the lifetime of batteries, for example.

To develop the material, the research team had to find a way to make bonds that are stable and reversible under electrochemical conditions. Most self-healing polymers use non-covalent bonds that are adversely affected by electrochemical reactions. The researchers found attractive forces that are stable under electrochemical conditions. They utilized bonding between charged chemical groups in a high-ionic-strength ionic liquid, and the polar regions of a stretchable polymer, the team says. The result is a material with the desired combination of properties.

The research team says the rubber-like material is low-cost, easy to produce and can stretch to 50 times its original length. After being cut, the material can re-attach completely in 24 hours at ambient conditions, the researchers say.

DIGITAL GAS PLANTS

Last month, Air Liquide (Paris, France; www.airliquide.com) inaugurated an operation center that is unique in the industrial gas sector. The operation center enables the remote management of production for 22 of the group's units in France, optimizing their energy consumption and improving their reliability.

Located near Lyon, the remote operation and optimization center can stop or restart a site remotely, as well as adapting — in realtime — the production level of the plants according to user demand. Through the analysis of big data, collected 24/7 for 22 sites in France, Air Liquide is developing predic-

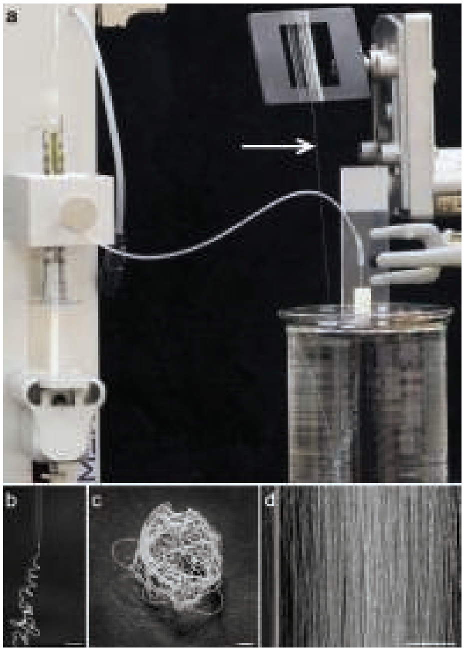
(Continues on p. 12)

Spinning miles of synthetic spider silk

An international team of scientists, led by senior researcher Anna Rising and professor Jan Johansson at the Swedish University of Agricultural Sciences and the Karolinska Institute (both Stockholm, Sweden; www.slu.se and www.ki.se), has developed a process that makes it possible to spin kilometer-long fibers of a chimeric recombinant spider silk protein. The achievement — published in *Nature Chemical Biology* — is expected to pave the way for a number of applications that take advantage of spider silk, which is lightweight yet stronger than steel. It is well tolerated when implanted in tissue and is biodegradable. Prior to this, it had not been possible to make long threads of artificial spider silk in a biomimetic way due to the low solubility of the proteins in water.

The process mimics the spinning mechanism of native spiders, which involves a pH gradient from 7.6 to less than 5.7 along the spider silk glands. The starting protein — a minispidroin composed of an NT (N-terminal domain) from *E. australis* MaSp1 and a CT (C-terminal domain) from *A. ventricosus* MiSp — is prepared in cultures of *E. coli*, producing 125 mg/L of protein (after purification).

To biomimic the spinning process, the protein is fed through a capillary (10–30-µm tip size) into an acidic buffer bath, and the fibers are drawn from the liquid and rolled onto frames (photo, a and b). Depending on the tip diameter, fibers can be produced



Swedish University of Agricultural Sciences

with diameters of 40 µm (photo, b and c) and 15 µm (photo, d).

"In the future, this may allow industrial production of artificial spider silk for biomaterial applications or for the manufacturing of advanced textiles," says Rising. Industrial partners are now being sought.

This project aims for high-efficiency enzyme production

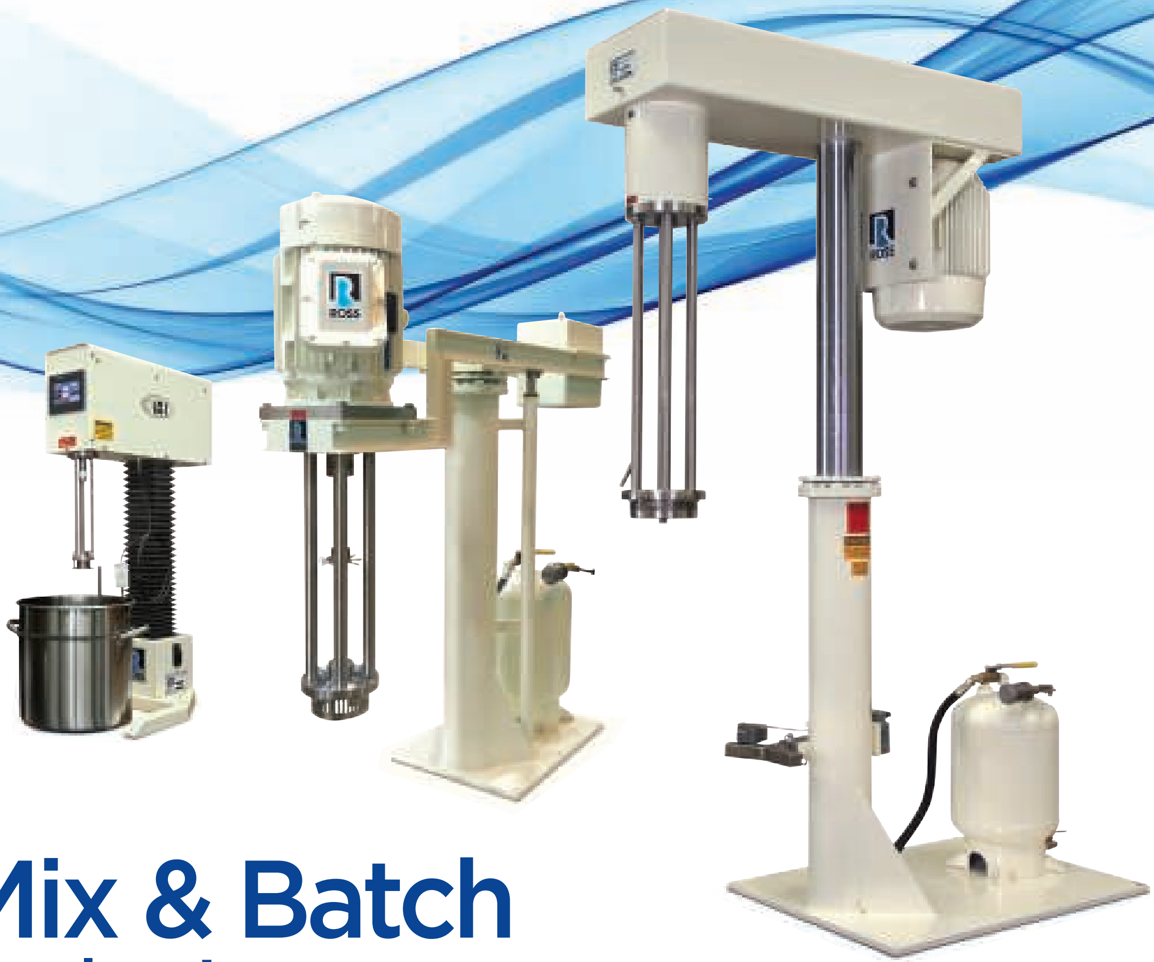
The European Union's Horizon 2020 Research and Innovation program has awarded a grant to a consortium working to raise yields and lower costs of large-scale industrial enzymes. The grant will fund a three-year project to increase yields of an enzyme product derived from *Myceliophthora thermophilia C1*, a microbe used in the production of biologically sourced natural gas (biomethane) from organic waste.

Currently available enzymes have not specifically been developed for the production of biogas, project leaders say, and therefore have not met expectations. The enzyme product derived from *M. thermophilia* has shown the ability to reduce the cost of producing biogas from organic waste by 10%, project leaders say, but yields have been too low to make it viable for industrial-scale production.

The objectives of the enzyme project, known as Demeter (www.demeter-eu-project.eu), are to increase the yield of this industrial fermentation process by at least 20%, improve the product recovery process by 40% and reduce overall product cost by at least 15%. To accomplish this, the project will follow a multi-scale approach, where enzyme productivity will be improved at the laboratory scale and in small pilot plants, while obtaining insights for further scale-up, says the research team. In parallel, the effect of enzymes on biogas yield will be quantified, using five commonly used biomass substrates.

The Demeter project team plans to demonstrate the improved fermentation and downstream process in a 15,000-L pilot plant and to demonstrate use of the enzyme in eight field trials at European biogas plants.

Demeter consortium partners include enzyme producer Genencor International, enzyme retailer Miavit, pilot plant facility BioBase Europe Pilot Plant, anaerobic digester expert OWS, and independent biogas research center DBFZ, along with Ciaotech for independent economic and environmental evaluation, and a large farm, Biomoer, for field trials.



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A new filter mesh with reduced erosion — by design

GKD

Porometric mesh is a new weave mesh designed by GKD-USA, Inc. (Cambridge, Md.; www.gkdusa.com) using computational fluid dynamics (CFD) simulations (photo), in a study aimed at reducing erosion and abrasion caused by sand in oil-and-gas pipelines. Porometric mesh has a very open, 3-D mesh construction that, while maintaining a constant volumetric flowrate, reduces local pore velocity by up to 40% compared to conventional filtration meshes, with throughput increasing by a similar factor, says the company. With a pore size of 150 µm, this new mesh type achieves an air permeability of 4,800 L/m^2/s at a pressure of 200 Pa. In contrast, a plain weave with the same pore size has a permeability level of only 2,500 L/m^2/s at 200 Pa. So, at the same volumetric flowrate, the more-open structure of the new mesh almost halves the local pore velocity. The lower maximum pore velocity results in lower wear of the filter material from particles.

Currently, the company offers Porometric mesh with a geometric pore opening of 150 and 175 µm, and the mesh is now undergoing practical tests that are confirming the values calculated in the simulation. The company is also working on a Porometric mesh family with pore sizes between 20 and 750 µm.

Batch or continuous? This methodology can help making the decision

So far, there is no high-level evaluation that gives a simple guideline on the benefits and feasibility of converting a batch to a continuous process. Now a group from the Agency for Science, Technology and Research (A*STAR; Singapore; www.ices.a-star.edu.sg) has developed a practical methodology that enables a process-development team to evaluate its existing batch process holistically. This can be especially valuable for fine chemicals and pharmaceuticals industries that might want to look into the possibility of achieving step-change improvements in an existing process to address cost and regulatory concerns.

The group's proposed methodology consists of three stages: initial screening, extended evaluation and process execution. The initial screening aims to uncover key business requirements and potential pitfalls, such as sticky reagents, with simple yes/no/maybe evaluations. Successful candidates are then broken down into flowchart analysis that identifies issues such as possible equipment and control schemes. If the analysis makes economic sense, a final stage of process execution is put in place.

The A*STAR group has applied its methodology to three reactions with fairly complex molecules that have been operated in the group's laboratories at both batch and continuous mode. The reactions are: synthesis of β-hydroxyester via the Reformatsky route; synthesis of 4,D-erythronolactone; and phase-transfer catalysis of O-alkylation of 3-phenyl-10-propanol.

Liquid-phase reactions that proceed quickly and release or absorb large quantities of energy proved to be particularly favorable for continuous processing. For example, the group showed that the Reformatsky reaction — an organo-zinc-catalyzed reaction that frequently overheats with batch processing — could profit from a continuous approach.

Heap leaching targets nickel from laterite

The NiWest Nickel Laterite Project located at Murrin Murrin in the North Eastern Goldfields of Western Australia, has the potential to become a significant long-term, low-cost nickel producer through the development of heap leaching. The project is 100% owned by GME Resources Ltd. (Fremantle; www.gmeresources.com.au) through its subsidiary NiWest Ltd.

Total metal content of more than 1,000,000 metric tons of nickel has been defined by extensive drilling programs. While most laterites have a high iron content of about 40%, Murrin Murrin has an iron content of about 18%.

The project will be a heap leaching operation combined with a processing plant utilizing direct solvent extraction and electrowinning to upgrade purified nickel solutions from the heap leach to produce LME (London Metal Exchange) nickel cathode. GME Resources has also developed and patented a regeneration and laterite-agglomeration technology that will enable all ore types to become heap leachable.

Multistage leaching of the ore will produce LME cathode nickel as well as a cobalt carbonate precipitate after being exposed to acid regeneration, the removal of iron, neutralization and solvent extraction before finishing up with electrowinning. The heap-leach solution circuit will include the removal of iron and the acid-regeneration process through its use of a dynamic on-off pad system where the spent ore and residue will be removed and discarded into a pit.

A scoping study highlighted that the proposed processing route offers a significantly lower capital cost over the alternative and more complex high-pressure acid-leach process. The NiWest processing plant will be capable of producing 540 m.t./yr of cobalt carbonate and 14,000 m.t./yr of nickel cathode. The mine life will be longer than 20 years.

A new adsorbent for wastewater treatment

A team at the Graduate School of Energy, Environment, Water and Sustainability (EEWS) of Korea Advanced Institute of Science and Technology (KAIST, Daejeon; www.kaist.ac.kr), led by professor Cafer T. Yavuz has developed a water-treatment adsorbent that can selectively remove water-soluble micromolecules, such as those of dyes and pesticides, which cannot be removed completely during conventional water-treatment processes. The adsorbent has the added advantages of being inexpensive, easily synthesized and renewable.

In order to remove very small molecules — which also tend to be electrically charged — with high solubility in water, and to do so selectively, the team had to develop a new adsorbent technology. It developed a fluorine-based nanoporous polymer that has all the desirable properties. By controlling the size of the pores, this adsorbent can selectively adsorb aqueous micromolecules of less than 1–2 nm in size.

To separate specific contaminants, the adsorbent had to be able to interact strongly with the target substance. Fluorine, the most electronegative atom, interacts strongly with charged soluble organic molecules. The incorporation of fluorine enabled the adsorbent to separate charged organic molecules up to eight times faster than neutral molecules.

The adsorbent could see wide industrial application, such as in batch-adsorption tests, and in column separation for size- and charge-specific adsorption. Yavuz says the charge-selective properties of fluorine could be used in desalination or water-treatment processes using membranes.

Chemicals from bagasse

Toray Industries, Inc. (www.toray.us) and Mitsui Sugar Co. (both Tokyo, Japan; www.mitsui-sugar.co.jp) have started a six-year project to demonstrate the production of useful materials from bagasse, with support from the New Energy and Industrial Technology Development Org. (NEDO; Kawasaki City, Japan; www.nedo.go.jp). Cellulose Biomass Technology Co. (CBT) — a joint venture (JV) established by Toray (67%) and Mitsui Sugar (33%) — plans to demonstrate the production of cellulosic sugar from the waste bagasse that is generated at the sugar factory. The cellulosic sugar will then be used as feedstock for making other useful chemicals.

A demonstration plant is being constructed that will include pulverization, pretreatment, enzyme-saccharization and membrane-separation processes, and will process 15 ton/d of dried bagasse, which corresponds to the production of 1,400 ton/yr of cellulose sugar.

Among the new technologies to be demonstrated are: energy-saving, membrane-based separation technology, developed by Toray; and extraction technology, developed by Mitsui Sugar. The high-quality cellulose sugar product can be used as a feedstock for making useful bio-chemicals and chemicals, such as ethanol, lactic acid, succinic acid, poly-phenol and phenol compounds.

tive maintenance for production sites by identifying the weak signals that precede a malfunction. Algorithms devised by Air Liquide engineers are used to fine-tune equipment adjustments in plants in order to optimize energy consumption, leveraging nearly 15 years of data gathered from all industrial sites. In the plants, new technologies (touch tablets, 3-D scanning, video tutorials and so on) are also being introduced to simplify maintenance and inspection management operations and the organization of daily tasks for operators.

WASTEWATER TREATMENT

Catexel (www.catexel.com) has secured two patents to protect manganese and iron complexes capable of generating chlorine dioxide from chloride salts. The technology could enable more efficient onsite generation of ClO_2 for the prevention of bacterial contamination and biofilm formation. The technology is said to have the potential to reduce the chemical load and deliver significant energy savings in wastewater treatment. ❑

New technique simplifies doping for organic semiconductors

A new solution-based method for introducing doping into organic semiconductor films could simplify the manufacture of efficient single-layer photovoltaic cells and move them closer to a commercial reality. Beyond solar cells, the doping technique could be more broadly used in other areas of organic electronics.

Developed by a team of researchers at the Georgia Institute of Technology (Atlanta; www.gatech.edu), along with partners at three other institutions, the technique could expand the potential applications for this technology, such as wearable electronics and small-scale, distributed power generation.

The process involves immersing organic semiconductor films into nitromethane solutions of polyoxometalates, which are polyanions containing transition metals (tungsten or molybdenum atoms, in this case). When exposed to the solution for several minutes, the metal atoms diffuse into the organic film, leading to efficient p-type (electron hole) electrical doping to a depth of 10–20 nm from the surface of the film, the researchers say.

"The p-doped regions show increased electrical conductivity and high work function, reduced solubility in the processing solvent, and improved photo-oxidation stability in air," says the Georgia Tech team.

Electrical doping of organic semiconductors is traditionally accomplished using vacuum-based techniques, which require costly equipment. This solution immersion method provides a simpler alternative to air-sensitive molybdenum oxide layers used in the most efficient polymer solar cells, the researchers say.

Sponsored by the Office of Naval Research (Arlington, Va.; www.onr.navy.mil), the work was reported in a recent issue of *Nature Materials*. The research also involved scientists from the University of California at Santa Barbara, Kyushu University (Japan), and the Eindhoven University of Technology (the Netherlands). ■

Business News

Plant Watch

AkzoNobel announces startup of bio-steam facility at Delfzijl plant

February 13, 2017 — AkzoNobel N.V. (Amsterdam, the Netherlands; www.akzonobel.com) and utility company Eneco announced the startup of a bio-steam facility at AkzoNobel's Delfzijl site in the Netherlands. Eneco has converted its biomass plant into a combined heat and power (CHP) plant, which provides both electricity and steam from renewable biomass. Eneco's biomass plant processes around 300,000 metric tons per year (m.t./yr) of timber scrapped from demolition projects and waste to produce electricity and steam.

Veolia to build iron-removal water-treatment plant in Senegal

February 13, 2017 — Veolia (Paris, France; www.veolia.com), through subsidiaries OTV and SADE, has been awarded a contract to design and build an iron-removal water-treatment plant in Dakar, Senegal for Société Nationale des Eaux du Sénégal. The facility will have a daily capacity of 40,000 m^3 of water. Treatment will consist of raw water aeration, physical-chemical treatment and sand filtration, followed by disinfection using chlorine produced onsite by electrochlorination. The contract represents revenue of €7.6 million.

Archroma expands capacity for tetrasulfonated brightening agents

February 9, 2017 — Archroma (Reinach, Switzerland; www.archroma.com) will invest in a new production facility for tetrasulfonated optical brightening agents at its existing production site in Prat del Llobregat, Spain. The new capacity is expected to come onstream in May 2017, and is designed to be further extended over the next few years.

Amec Foster Wheeler wins boiler contract for Louisiana methanol plant

February 3, 2017 — Amec Foster Wheeler's (London, U.K.; www.amecfw.com) Global Power Group (GPG) has been awarded a contract from Yuhuang Chemical Inc. (YCI) for the design and supply of an auxiliary boiler that will provide 580,000 lb/h of steam for the first phase of YCI's methanol facility in St. James Parish, La. In addition to the boiler, the scope of supply includes the fan, ductwork, combustion system and selective catalytic-reduction equipment.

Air Products to boost liquid nitrogen production at Middletown, Ohio plant

January 31, 2017 — Air Products (Lehigh Valley, Pa.; www.airproducts.com) plans to install a new liquefier at its air separation plant located in Middletown, Ohio to increase liquid nitrogen production. The new liquefier is to be onstream in October 2018. This investment will add hundreds of tons per day of liquid nitrogen capacity.

Chandra Asri selects Unipol PE process technology for new polyethylene plant

January 31, 2017 — PT Chandra Asri Petrochemical Tbk (CAP; Jakarta, Indonesia; www.chandra-asri.com), has selected Univation Technologies' Unipol PE Process for its new polyethylene plant that will be built in Cilegon, Indonesia, at CAP's Naphtha Cracker Complex. The plant's capacity will be 400,000 m.t./yr. This will be the second Unipol PE Process line for CAP.

Momentive breaks ground in Leverkusen for new silane plant

January 30, 2017 — Momentive Performance Materials Inc. (Waterford, N.Y.; www.momentive.com) broke ground on a new dedicated manufacturing facility for silane products in Leverkusen, Germany. Momentive will invest approximately $30 million in the plant, which is expected to begin production in late 2017.

Tosoh announces PVC capacity expansion in the Philippines

January 27, 2017 — Philippine Resins Industries, Inc. (PRII), a subsidiary of Tosoh Group (Tokyo, Japan; www.tosoh.com), plans to increase its polyvinyl chloride (PVC) production capacity. Completion of construction for the additional PVC manufacturing facilities is expected in December 2018. The new facilities will add 110,000 m.t./yr of PVC, doubling PRII's PVC production capacity. Commercial operations are to start in January 2019.

Mergers & Acquisitions

Victrex establishes JV for polyketone composites production

February 9, 2017 — Victrex plc (Thornton Cleveleys, U.K.; www.victrex.com) and Tri-Mack Plastics Manufacturing Corp. have established a joint venture (JV), TxV Aero Composites, to accelerate the commercial adoption of polyketone composite applications within the aerospace industry. The multi-million- dollar investment includes the establishment of a new U.S.-based manufacturing facility.

BASF acquires photoalignment materials provider Rolic

February 8, 2017 — BASF SE (Ludwigshafen, Germany; www.basf.com) has acquired Rolic AG (Allschwil, Switzerland), a provider of photoalignment materials. The transaction includes Rolic's affiliates in Eindhoven, the Netherlands and Shanghai, China. Both companies have agreed not to disclose financial details of the transaction.

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Pentair acquires carbon-capture specialist Union Engineering
February 3, 2017 — Pentair plc (Manchester, U.K.; www.pentair.com) has completed the acquisition of Union Engineering A/S (Fredericia, Denmark), which specializes in capturing, recovering and purifying carbon dioxide. Union Engineering has offices in China, Brazil and the U.S.

Dow to divest EAA copolymers business
February 2, 2017 — The Dow Chemical Co. (Midland, Mich.; www.dow.com) agreed to sell its global ethylene acrylic acid (EAA) copolymers and ionomers business to SK Innovation (Seoul, South Korea; www.skinnovation.com). The divestiture agreement includes production assets located in Freeport, Tex., and Tarragona, Spain.

Solvay acquires Energain Li-ion technology from DuPont
February 1, 2017 — Solvay S.A. (Brussels, Belgium; www.solvay.com) announced the acquisition of Energain Li-ion high-voltage technology from DuPont (Wilmington, Del.; www.dupont.com). Energain technology and formulations enlarge Solvay's existing portfolio of salts and additives for electrolytes.

Braskem to acquire Cetrel shares from Odebrecht
January 31, 2017 — Braskem (São Paulo, Brazil; www.braskem.com.br) will acquire a controlling interest Odebrecht Utilities' Cetrel business unit. Cetrel is responsible for waste treatment and disposal, environmental monitoring and water supply at Braskem's Camaçari Petrochemical Complex. Under the agreement, Braskem will acquire 63.7% of the Cetrel shares held by Odebrecht for around $195 million.

Sumitomo Chemical buys out Trinseo stake in SSPC JV
January 26, 2017 — Trinseo S.A. (Berwyn, Pa.; www.trinseo.com) and Sumitomo Chemical Co. (Tokyo; www.sumitomo-chem.co.jp) have signed a definitive agreement for Trinseo to sell its 50% share in their Sumika Styron Polycarbonate (SSPC) JV to Sumitomo Chemical for an undisclosed price. SSPC produces polycarbonate resins at production facilities in Niihama City, Ehime, Japan.

Ineos announces intent to acquire Arkema's Oxo Alcohol business
January 26, 2017 — Ineos (Rolle, Switzerland; www.ineos.com) plans to acquire Arkema's (Colombes, France; www.arkema.com) Oxo Alcohol business, which will include the acquisition of Arkema's stake in Oxochimie, a JV between Ineos and Arkema that produces butanol and 2-ethyl hexanol.

Shell to sell stake in Sadaf Chemicals JV in Saudi Arabia
January 22, 2017 — Sabic (Riyadh, Saudia Arabia; www.sabic.com) will acquire Shell's (The Hague, the Netherlands; www.shell.com) 50% share in the companies' Sadaf petrochemicals JV for $820 million. The Sadaf JV encompasses six petrochemical plants with a total output of more than 4 million m.t./yr. ■

Mary Page Bailey

Refrigerants: New Rules Reinforce Innovation

As new regulations take effect, familiar refrigerants are being phased out and a variety of next-generation materials and processes are being introduced

Chemours

FIGURE 1. Chemours breaks ground on a major production site for low-GWP HFO refrigerants

IN BRIEF

Agreed upon in October 2016 after negotiations from over 170 nations, the Kigali Amendment to the Montreal Protocol seeks to phase out the use of hydrofluorocarbon (HFC) refrigerants due to their high global-warming potential (GWP), paving the way for newer, low-GWP refrigerant materials to enter the marketplace. Although the Kigali Amendment is certainly the most prominent refrigerant-related ruling in recent years, several other regulations focused on reducing the use of high-GWP chemical refrigerants have been implemented, including major delistings of HFCs in Europe, the U.S. and Japan. This article provides perspective on low-GWP refrigerants and some attendant operational considerations, and also highlights two refrigerant-free cooling technologies.

Growth in HFOs

Although the Kigali Amendment was not finalized until late last year, the industry has been preparing for an eventual phasedown of HFCs for many years. Manufacturing capacity for low-GWP hydrofluoroolefin (HFO) refrigerants is set to ramp up significantly in the coming years, thanks to investments from companies like Honeywell (Morris Plains, N.J.; www.honeywell.com) and The Chemours Co. (Wilmington, Del.; www.chemours.com).

"Honeywell anticipated the need for next-generation replacements to HFCs more than a decade ago, and has invested $900 million in R&D and new capacity to produce HFC alternatives," says Rajiv Banavali, vice president and chief technical officer for Honeywell Advanced Materials. The company is nearing startup of what is said to be the world's largest manufacturing site for next-generation mobile air-conditioning refrigerants in Geismar, La.

"There are multiple factors involved in phasing down a generation of substances like HFCs," says Banavali, including costs, the availability of replacement substances, the resources required to produce replacements and the readiness of current applications to accept replacements without significant retrofitting. To make the transition to new refrigerants as seamless as possible, HFO producers strive to make their products "drop-in" replacements for legacy refrigerants, and Honeywell's Solstice suite of HFO-based products has been reviewed by several regulatory and industrial organizations for use in the intended applications. Low- and medium-pressure chillers are an area where Solstice products have been especially adaptable, as 15 chiller manufacturers have launched models based on Solstice refrigerants, says Banavali. Increased energy efficiency is also possible with HFOs in some applications, he explains, describing medium-temperature supermarket refrigerant applications as an area where HFO blends have demonstrated as much as 16% lower energy consumption when compared with previous refrigerants.

In February, Chemours broke ground in Ingleside, Tex. for a new manufacturing facility to produce the low-GWP refrigerant

Jason Richards, Oak Ridge National Laboratory, U.S. Dept. of Energy

FIGURE 2. The magnetocaloric refrigeration system being developed at ORNL uses a magnetic field to remove heat

HFO-1234yf, tripling the company's global capacity (Figure 1). The new plant is expected to start production in the third quarter of 2018. "The new HFO manufacturing processes are directionally similar to incumbent HFC processes; although various additional manufacturing steps are included, making them generally more complex," says Diego Boeri, vice president of Chemours' Fluorochemicals business.

Chemours was the first supplier to commercially produce HFO-1234yf, initially starting in 2011 from a facility in Japan. Since then, the industry has seen the introduction of numerous environmental regulations, making investments in low-GWP solutions all the more crucial. Chemours' Opteon low-GWP product line was initially driven by mobile air-conditioning applications, but has seen an increase in more complex applications on the horizon. "Chemours is actively developing several new refrigerant fluids based on HFO-1336mzz technology for a variety of applications, including traditional chiller systems and the emerging arena of waste-heat recovery, such as high-temperature heat pumps and organic Rankine cycles," comments Boeri.

In India, SRF Ltd. (Gurgaon, India; www.sfr.com) is constructing a pilot plant to demonstrate a new HFO-1234yf manufacturing process. "SRF is one of the very few companies to develop its own technology for manufacturing HFO-1234yf," says Prashant Yadav, president and CEO of SRF's Fluorochemicals & Engineering Plastics business. Based on market needs in India, SRF will progress to commercial-scale manufacturing, mentions Yadav, citing rising car production as an accelerator for refrigerant demand. "SRF is preparing to meet this expected rise in demand in the future with next-generation low-GWP refrigerants," he says.

Compatibility factors

As industries begin implementing new refrigerants, additional operational considerations must be reviewed, including compatibility with lubricating oils and other auxiliary chemicals. A group from JX Nippon Oil & Energy Corp. (NOE; Tokyo; www.noe.jx-group.co.jp) is developing polyol ester (POE) refrigerant oils specifically for use with HFO refrigerants. "Refrigeration oils are generally required to have good miscibility with the refrigerant, good lubricity and chemical stability under the refrigerant atmospheres. In the case of HFO refrigerants, the chemical stability could be a problem," says Akira Tada, an engineer with NOE's Grease & Refrigeration Oil R&D Group. Tada cites HFOs' double bonds as the source of these instability concerns, as they increase the refrigerants' likelihood of decomposition when compared to HFCs. "If air gets into refrigeration systems using HFOs, the decomposition of HFOs proceeds drastically, and it leads to the formation of hydrogen fluoride," he explains. The presence of hydrogen fluoride not only accelerates the degradation of refrigeration oils, it also can attack the system's materials of construction, resulting in serious operational problems. It is these concerns driving NOE's development of new refrigeration oils for use with HFOs.

New additive formulations have given way to POE oils that have shown high chemical stability under HFO atmospheres, even when contaminated by air. Furthermore, low miscibility of oils with refrigerants can generally lead to separation at low temperatures, which can cause congestion of oil in capillaries and decrease the amount of oil in the compressor. However, these new oils exhibit good miscibility and lubricity with HFOs, and are also compatible with HFCs and HFC-HFO mixtures. Tada's team is currently conducting trials of these oils with clients to evaluate for commercial use.

Potential compatibility problems can be introduced long before systems are running — for instance, the chemistry of metalworking fluids (MWFs) used in fabricating refrigeration equipment can negatively impact operations. Residual MWFs may become mixed into refrigerant and compressor lubricants, causing inefficiencies and premature failures. A team of engineers from Chemtool Inc. (Rockton, Ill.; www.chemtool.com) and CPI Fluid Engineering (Midland, Mich.; www.cpieng.com) has been studying the effects of MWFs on refrigeration systems. "Each MWF and metal-cleaning solution should be evaluated before doing any refrigeration machining, parts washing or even applying metal protective film during manufacture and assembly," explains Richard Butler, Chemtool fluids technical manager. The researchers' findings indicated that some MWFs, such as those containing chlorinated alkanes, could still cause corrosion even after parts are washed, leading the team to recommend the use of functional alternatives. The effects of MWF-derived corrosion in refrigeration processes can be severe, describes Butler: "Increased acid number will cause oxidation and degradation of the compressor lubricant. Similarly, corrosion of ferrous materials will produce abrasive particles, leading to premature compressor failure." For common refrigerants, like R134a and R410A, compatible MWFs and lube oils do exist, says Butler. However, further work remains in the area of next-generation refrigerants. The team's next project will include compatibility tests for the low-GWP refrigerant HFO-1234yf, as well as an expansion to evaluate more metals, including aluminum and copper.

Beyond the compression cycle

A handful of new cooling technologies forgo some of the concerns associated with refrigerants by eliminating them altogether. Oak Ridge National Laboratory (ORNL; Oak Ridge,

Tenn.; www.ornl.gov) is developing one such technology, leveraging a thermal phenomenon known as the magnetocaloric effect. The key to magnetocaloric cooling is the precise application of a magnetic field to specialized powdered metallic materials. The magnetocaloric materials can expel and absorb heat through a cycle of being magnetized and de-magnetized. "Studies have shown that these materials have the potential to be 20–25% more efficient than conventional vapor-compression systems," says Ayyoub Momen, lead researcher for ORNL's magnetocaloric refrigeration project, which is working along with GE Appliances toward commercializing the first magnetocaloric refrigerator. "When you put these materials inside of a magnetic field, their temperature suddenly goes up," explains Momen, "but when you remove the magnet, their temperature goes down." The project aims at leveraging this cooling effect in a refrigerator. The critical property for magnetocaloric materials is the temperature at which they lose their magnetism, or the Curie temperature. Researchers at ORNL have fine-tuned cooling performance by layering as many as 15–20 different magnetocaloric materials based on their Curie temperatures to expand the temperature span of the refrigerator, says Momen.

Beyond manipulating the magnetocaloric materials to improve their cooling behavior, a second facet of the research is to design the refrigeration machine itself (Figure 2). Inside the refrigeration process, the magnetocaloric materials are periodically magnetized and de-magnetized while a working fluid, such as water or glycol or a mixture of the two, moves into and out of the system. As the fluid passes through the particulate materials, on one side, a cooling effect is generated, while the other side generates a heating effect. Analogous to a vapor-compression refrigeration cycle, here, the cool side acts as the evaporator and the hot side acts as the condenser.

"One of the main challenges, from a performance point of view, is the pressure drop," says Momen. Other design challenges he mentions are the complex valving system required for the process and optimizing the design to bring down system costs. "It is iterative research that we are performing right now," he explains. The system's overall safety is another advantage, since the magnets are shielded, making exposure to the magnetic field unlikely. Also, the use of the innocuous working fluids and solid magnetocaloric "refrigerants" decreases leakage concerns. Additionally, the magnets and the refrigerant materials can be recycled when their service life is up, adds Momen. "The target is to make the system as robust as a conventional refrigerator with a lifetime of around ten to fifteen years," he explains. In addition to investigating magnetocaloric cooling for refrigerator applications, the ORNL team is also looking into scaling the system into a small air-conditioning unit.

Thermoelectric devices — those that leverage the heat flux between two materials of differing conductivity and require no refrigerant chemicals — are also being increasingly considered for cooling applications. A new refrigerated incubation system from Thermo Fisher Scientific Inc. (Waltham, Mass.; www.thermofisher.com) is based on the thermoelectric Peltier effect, providing both cooling and heating in a single module. The company developed the Peltier-based Heratherm incubator (Figure 3) in order to overcome some of the disadvantages of traditional compressor-based cooling processes used in similar products, explains Konrad Knauss, global product manager of Thermo Fisher's constant temperature products. Compressor-based systems are especially energy consuming when systems must regulate temperatures near ambient, because both the compressor and heating element run simultaneously to stabilize temperature. In tests conducted by Thermo Fisher, the Peltier units consumed a fifth of the energy required for running a compressor-based cooling system.

Unlike compressor systems, the Peltier system generates no vibrations. Another advantage is that the Peltier system generates very little heat exhaust, so its operation will not impact a laboratory's ambient conditions.

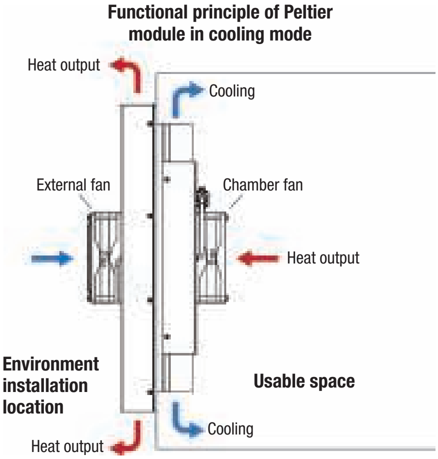


FIGURE 3. Based on Peltier thermoelectric technology, this refrigerated incubator consumes much less energy than a traditional compressor-based cooling system

Within the Peltier element, the connection between two metals with different electric conductivities promotes heating on one side and cooling on the other side. "In the refrigerated incubator, we switch the sides when we need cooling or heating — the cool side is on the inside, and the hot side is on the outside, and vice versa," explains Knauss. While the Peltier effect is extremely efficient in the near-ambient range, there are efficiency disadvantages when operating at extremely high or low temperatures, says Knauss.

Although Peltier cooling systems are available commercially for small-scale applications like household wine coolers, Knauss says refrigerated incubation is the first commercial application of the technology in the industrial science sector. Peltier Heratherm incubators are currently available in a 178-L benchtop model and a 381-L floor model, but with the addition of more internal Peltier elements, the system could effectively be expanded for higher capacities. According to Knauss, the company plans to eventually scale up the system for a larger offering, but there are several challenges to overcome with regard to cost and ease of operation. ■

Mary Page Bailey

Building a Better Burner

Burner manufacturers provide low-NOx equipment that meets both emissions and performance goals

IN BRIEF

BURNER IMPROVEMENTS

TIGHTER CONTROLS

HEAT RECOVERY EQUIPMENT

Several decades ago, regulatory action that necessitated reductions in oxides of nitrogen (NOx) from industrial sources led to the development of new technologies, such as low-NOx and ultra-low-NOx burners. In the years following, burner technologies were studied and changed until they were eventually able to achieve startlingly low levels of NOx emissions as mandated by ever tightening regulations. However, after actively using this specialized equipment in chemical and other processes for extended periods of time, both end users and burner manufacturers discovered that achieving these very low levels of NOx emissions often resulted in a tradeoff, in the form of reduced efficiency of the equipment. Now, burner manufacturers are working to improve the performance of low-NOx and ultra-low NOx burners.

Burner improvements

"Historically, process burners were supplied to provide heat to a process, so the requirement was simply to provide reliable heat and reliable combustion," explains Erwin Platvoet, process burner product director with John Zink Hamworthy Combustion (Tulsa, Okla.; www.johnzinkhamworthy.com). "However, in the early 1990s, emissions of [NOx] became very important and required a redesign of their burners in order to generate less nitrogen oxides."

Platvoet says the burner industry developed new fuel- and air-staging principles and combustion techniques that allowed burners to generate low NOx and found that within their own test furnaces, the burners achieved all emissions and performance goals. "But by the time these were in the field for several years, it was noted that a lot of the designs did not behave as well as older burners with simpler combustion principles," he says. "So for the last several years, the industry has begun to examine and understand what happens inside low- and ultra-low-NOx burners."

Platvoet says that the increasing feasibility of computational fluid dynamics (CFD) studies has allowed burner manufacturers to study what is transpiring inside process heaters when low- and ultra-low-NOx burners are placed inside. "CFD studies have revealed that, in many cases, the burners themselves are not the root cause for the issues, but more the way they are arranged inside the firebox, so rather than trying to build a better mousetrap to provide even lower NOx levels, burner manufacturers are focusing on how to improve existing designs. We have created rules-of-thumb for burner placement and firebox design that allow us to get much better behavior out of these burners," he says. "This better understanding of firebox aerodynamics and different arrangements inside the firebox allows us to not only lower emissions, but also to improve heat-flux profiles, prevent hot spots and improve the efficiency of this equipment."

For example, John Zink Hamworthy Combustion's COOLstar burner applies internal fluegas recirculation and fuel staging (Figure 1). This results in stable, compact flames and guaranteed NOx emissions as low as 15 parts per million by volume, dry (ppmvd) while minimizing CO emissions during startup and turndown conditions.

John Zink Hamworthy

FIGURE 1. The COOLstar burner applies internal fluegas recirculation and fuel staging, which results in stable, compact flames and low NOx emissions

Zeeco

FIGURE 2. The GB Single Jet burner is a staged, round-flame low-NOx burner that uses a non-symmetrical design to boost internal fluegas recirculation and staged air and fuel to reduce NOx emissions

Selas Heat Technologies

FIGURE 3. The Selas Isgad is an ultra-low NOx, flat-flame burner for a variety of applications

Parker Imel, a senior design engineer with Zeeco (Broken Arrow, Okla.; www.zeeco.com) says that burner manufacturers are making strides when it comes to improving the performance of low-NOx equipment. "We try to utilize as many design approaches as we can to reduce emissions in the burner while keeping in mind that these pieces of equipment are operated continuously, so they must be reliable. They also need to be efficient in the process and feature adequate flame patterns and heat transfer, so we are combining new technology with old technology to create the next generation of equipment."

As such, Zeeco offers the GB Single Jet burner, which is a staged, round flame low-NOx burner that uses a non-symmetrical design to boost internal fluegas recirculation and staged air and fuel to reduce NOx emissions (Figure 2). The burner's single-fuel gas tip and cone design offers high turndown, predictable flame characteristics and low probability of flame interaction. This design also preserves continuity with standing maintenance practices and operator training requirements for raw gas burners dating back to the 1950s.

Similarly, many burner manufacturers are finding ways to achieve lower emissions while improving burner efficiency and performance by introducing less excess air into the equipment or employing new methods of air staging.

"A common way to achieve low emissions in a burner is to add a lot of excess air, which reduces the flow temperature of the burner and produces less NOx, but throwing all that air into a burner consumes energy and it becomes an anchor on the efficiency of the burner, especially in indirect applications, such as when using a boiler to generate steam or a thermal fluid heater," notes Todd Ellerton, global product marketing director for thermal transfer systems with Honeywell Thermal Solutions (Morris Plains, N.J.; www.honeywell.com).

For applications where more efficiency and lower NOx emissions are a requirement, Ellerton says the Maxon Kinedizer LE may be a solution. The nozzle-mix, medium velocity design uses advanced mixing technology to produce low emissions with very little excess air. Built with a reinforced refractory block and steel burner body and nozzle, it burns natural gas, propane or other gaseous fuels. With turndown as high as 20:1, the burner can be used on oxidizers, process heaters, kilns, furnaces, dryers and other high-temperature applications.

Improved air staging is another method to reduce NOx without sacrificing performance, note the experts. "Staged air distribution allows us to reduce emissions because we are using a primary and a secondary air source as a way to start combustion while keeping the flame cool," says Chris Vandegrift, vice president of engineering and quality with Selas Heat Technologies (Streetsboro, Ohio; www.selas.com). "When the flame is cooler, you make less NOx, but we need heat in the burner to more efficiently complete the process, so air staging often led to that tradeoff between lower emissions and reduced performance. However, there are ways to improve air staging via premixing of gases that will keep NOx low and performance high."

He says there are different types of nozzle mix and premix burners available. In premix designs, the air and gas are together and will light immediately in the pipe, thus meeting emissions and performance goals. Nozzle mix means that air and gas have to be placed together in the burner itself, which is less efficient. "When you premix, all the mixing is done ahead of time, which creates a hotter flame that allows more efficient combustion and provides less time for NOx formation," says Vandegrift. "While this technology isn't always embraced, we've been trying to educate processors on the value of the premix technology, its increased efficiency and the safety of our system." The company's Isgad low-NOx hydrogen burner offers this type of technology (Figure 3).

In some situations, air staging can be used to offset fluegas recirculation, while still providing increased efficiency and low NOx emissions in natural draft burners. "While the use of fluegas is a good way to reduce NOx, a lot of processors place their process heaters outside, which creates a problem when temperatures are below freezing because the recir-

Metgec Systems

FIGURE 4. The Air Gas Ratio Control (AGRC) system measures and controls gas and air flows continuously through a PID loop to provide less energy use and lower emissions rates

cuated air brings in moisture, which can freeze in winter weather conditions, building up inside the ducts and fans and around the burner," says Joseph Arnold, head engineer with Faber Burner Co. (Lock Haven, Pa.; www.faberburner.com). "The way we've overcome this problem is to develop burners, such as our L2E burners, that don't require recirculation of fluegas but still meet less than 30 ppm emission guarantees. This burner runs off the principle of staging the entry of fuel into the burner at two different points, allowing us to achieve lower emissions without fluegas recirculation."

Gas is fired through a two-stage, fixed-center mounted gun and multiple spud system. He says as the burner fires, it creates natural currents within the furnace. The burner entrains some of the internal gas inside the furnace, which helps dilute the fuel and is referred to as "internal fluegas recirculation." This recirculation is enough to reduce emissions while preventing the efficiency problems caused by freezing in traditional recirculation situations.

Tighter controls

In the past, burners were simple devices that didn't require complex controls, but today's more complicated systems often require ratio regulators in order to optimize the burner and provide lower emissions, says Scott Latusek, application engineer with Megtec Systems (De Pere, Wis.; www.babcock.com/megtec). "The goal of ratio regula tors is to measure the amount of combustion air and fuel and provide the correct amount of combustion air for every possible flowrate during the process," he says. "This tighter control provides reduced fuel consumption while also providing better NOx performance."

Megtec provides the Air Gas Ratio Control (AGRC) system to measure and control gas and air flows continuously through a PID (proportion, integration, derivative) loop (Figure 4). The system provides low energy use and emissions rates. With most burner systems, the air-to-fuel ratio is set at the maximum firing rate of the burner and the minimum air flow is set at low fire position. Between these settings, the air and gas valves are usually controlled by the valve positions between these limits. This is done either mechanically with linkage or electronically through aprogrammable logic controller (PLC) or relay logic. While this method works, if the burner operates under its maximum firing rate, a significant amount of excess air is typically used and the burner operates outside of the stoichiometric ratio, resulting in higher fuel usage.

"Rather than mechanically linking combustion air and natural gas, we can have individual control and measurement of combustion air and natural gas and through PLC control, we can regulate the flow of each to maintain the optimum air-to-fuel ratio, maintaining a stable flame and minimizing production of combustion byproducts," says Latusek. In areas where low NOx is a requirement, this system can also maintain a burner in a low NOx state when it is combined with a low-NOx burner.

Honeywell's Ellerton agrees that controls, which permit the burner to work at its optimum in the full spectrum of conditions, will lead to better performance and lower emissions. The company's SLATE control technology provides configurable safety and programmable logic in one platform so it is adaptable to range of applications. "It includes integrated O_2 trends to maximize fuel efficiency and looks at the stack to optimize air-to-fuel ratio to make sure the burner is operating at a safe range and is providing the most efficient of optimum air-fuel ratios," explains Ellerton. "It also offers variable frequency drive (VFD) compatibility and control, so users can conserve energy on the combustion air blower and a range of valves and actuators are part of the system to help with precise control and overall performance optimization of the combustion system. Finally, it has Internet-based connectivity so customers can remotely access the system."

Epcon

FIGURE 5. Epcon specializes in creating systems that employ heat-recovery techniques, such as this fabrication of a custom high-efficiency tube-and-shell, air-to-air heat exchanger.

Heat-recovery equipment

"Previously, processors might not have been compelled to add primary heat recovery or secondary heat recovery for fuel savings because they thought they couldn't justify the expense based on fuel savings alone," says Vipul Patel, CPI sales application engineer with Epcon Industrial Systems (The Woodlands, Tex.; www.epconlp.com). "However, the objective to reduce NOx emissions is changing the [return on investment; (ROI)], dramatically, in some cases."

Patel says his company specializes in creating systems that employ heat-recovery techniques (Figure 5). Depending on the needs and goals of the process, some systems may use primary heat recovery, such as when a recuperative thermal oxidizer is used to preheat the process vent stream so that a larger burner doesn't need to be fired at higher rates to bring the process up to the operating set point. "In this type of system, we can often use a smaller burner to reduce the amount of NOx being generated," he says.

In other cases, secondary heat recovery can be integrated to improve efficiency and performance of the facility. There are a host of interesting ways to employ the recovered energy, from directing the hot secondary air to a curing or drying system or through the addition of a heat recovery steam generator/hot water generator on the back end of the thermal oxidizer. Regardless of which of these strategies is employed, using this energy in other parts of the plant offers the potential to eliminate or greatly reduce the size of a burner elsewhere in the plant, resulting in a reduction in the overall NOx emissions for the plant.

"Heat recovery, whether it's primary heat recovery or secondary heat recovery, can be an invaluable method of reducing the burner load and/or reducing the burner size, therefore reducing the net NOx emission level for the facility, allowing the processor to stay within the total site NOx limit," says Patel. "So clearly, heat recovery can be used as a NOx-reduction strategy that will also help improve efficiency of the plant, both of which provide the ROI many processors are seeking."

While NOx emissions limits vary from location to location, ensuring that burner users meet those limits while employing a combustion system that is appropriate to achieve targeted product quality and production rate is equally important. "We in the burner industry are working on achieving this by trying to understand every detailed level of burner performance, as well as the customer's process and their expectations of the combustion system," says Platvoet. "It is critical to do so if we're going to achieve continually tightening emissions levels as well as top-notch burner performance." ■

CE Staff

Laboratory Equipment

MilliporeSigma

Speakman

AirScience

Disposable filtration units handle a range of fluids

This company has recently expanded its portfolio of EZ-Fit filtration units (photo). These ready-to-use, disposable filtration devices are designed for bioburden testing. The newer EZ-Fit pink filtration units come with a wide range of membrane sizes to suit many applications, and they feature a new patented drain design to accelerate processing of turbid or hard-to-filter matrices. Both the newer pink and the original blue units are said to conform to international standards (USP/EP) and water-testing regulations, and can be used for filtration of liquid samples, including water, raw materials, in-process samples and final products. They are available in 100-mL and 250-mL funnel sizes. The optimized membrane remains perfectly flat after filtration to stay in constant contact with the culture media, says the manufacturer. — *MilliporeSigma, Billerica, Mass.*
www.emdgroup.com

Emergency shower heads ensure complete draining

The Lifesaver Emergency Shower Head (photo) is designed for laboratories, industrial buildings and other settings that require emergency shower capabilities. Its spray engine delivers water quickly in a stream that is forceful but comfortable enough for the user to stand under the spray for a full 15 minutes (the amount of time required to ensure effective washing after exposure to hazardous chemicals), says the company. It features an integral flow regulator that controls water flow to 20 gal/min. Its integral flow-control capabilities allow for simultaneous emergency shower head and eyewash use. Three versions are available: 80-in., bright yellow ABS plastic, 8-in. stainless-steel finish, and 1-in. stainless-steel finish (featured on recessed shower and combination units). — *Speakman, New Castle, Del.*
www.speakman.com

Compact laboratory hood offers many filter options

The DWS Downflow Workstations (photo) ensure safety and low noise levels for laboratory operators. They recirculate air (rather than discharging expensive conditioned air to the atmosphere). This reduces HVAC strain and lowers overhead costs, says the company. The DWS Workstations are designed to provide a small bench-mounted unit with unrestricted access for operations that may be hard to perform in a conventional fume hood. A variety of filters can be selected to meet the needs of the laboratory; these include 14 different types of carbon and specialty media for vapors such as organics, solvents, acids, mercury and formaldehyde. HEPA filters for particulate filtration are also available. — *AirScience, Fort Myers, Fla.*
www.airscience.com

Measure chemical concentration with this unit

Anton Paar

The DMA 4500 M chemicals meter (photo) measures concentration from the measured density, and has 140 built-in concentration tables covering salts, acids, alkalis, alcohols, sugar and more. Individual tables can be added at any time. The meter provides fully automated sample changing and data processing, and its touch screen technology uses chemically hardened glass for maximum protection. It requires a small sample volume (2 mL) and delivers fast results (30 s), and the automated conversion of the density reading into a concentration value elminates human error, says the manufacturer. — *Anton Paar USA, Ashland, Va.*
www.anton-paar.com

Note: For more information, circle the 3-digit number on p. 90, or use the website designation.

Digital video camera captures the action in your microscope

Fastec Imaging

This company's IL5 High-Speed Camera (photo; p. 32) is easily mounted on a micrscope, enabling users to record high-speed video of microscopic events. Both spatial and temporal magnification work in tandem to clarify understanding in applications such as microfluidics, where particles often move through the field of view very quickly, says the company. With four models to choose from, each records over 3,200 frames per second (fps) at VGA resolution, and more than 29,000 frames per second at lower resolution. Able to save images to an SSD or SD card while recording high-speed bursts of hundreds or even thousands of images at a time, the IL5 captures high-speed snapshots of high-speed events, in addition to video. The Fastec IL5 camera can be controlled over Gigabit Ethernet via Fastec software on a PC or Mac, or via the built-in web interface with any web browser on a PC, Mac, tablet or even smartphone. Unlike traditional high-speed camera systems that only record for a few seconds and require careful triggering, the IL5's Long-Record (LR) option can record at high speed for many minutes at high resolution, to many hours at lower resolution. — *Fastec Imaging, San Diego, Calif.*
www.fastecimaging.com

Compact, benchtop system provides formulation analysis

The ability to test the aging and shelf life of emulsions, suspensions, dispersions and foams is a critical step in research and development and quality control, across a wide range of chemical process operations, including cosmetics, inks and cosmetics production. Many traditional testing methods are reliable, but do not provide quick results needed during product formulation and manufacturing. The Turbiscan family of stability analyzers includes the Turbiscan TLAb (photo), which is a compact, benchtop model with temperature regulation. It is designed to detect all types of destabilization, including coalescence, flocculation, creaming, sedimentation and more. Three versions are available, to providing a range of features that enable quick, convenient characterization of concentrated dispersions, says the company. The device lets users carry out quick, single-point measurement to enable a rapid signature (sample fingerprint) of the product being analyzed. Rapid results are especially essential during quality control, says the company.— *Fullbrook Systems Ltd., Hemel Hempstead, U.K.*
www.fullbrooksystems.com

Automate tube decapping and barcode identification

Hamilton Storage

This company has recently upgraded its LabElite DeCapper (photo) to improve workflow efficiencies in tube-based sample management. Its six-channel head enables use of 24-well tube racks on the LabElite DeCapper and I.D. Capper, in addition to 48- and 96-well tube racks. A variety of internally or externally threaded microtubes, cryovials and specialty tubes can be rapidly decapped and capped, so that laboratories can work with tube volumes and types that are appropriate for their applications. The compact LabElite I.D. Capper adds efficiency by combining decapping/capping and high-speed 2-D barcode reading without the need for additional hardware. These devices are designed for applications

Hemco

Hüber Kältemaschinenbau

Powder Systems

such as biobanking, forensics, genomics, drug discovery and life science research. — *Hamilton Storage, Franklin, Mass.*
www.hamiltoncompany.com

Walk-in fume hoods accommodate large systems

The UniMax Floor Mount Hoods (photo) have recently been expanded to include a wider selection of models that feature fire-suppression systems. Standard models range from 6–24 ft wide, 4–8 ft deep, and 7–16 ft high. These hoods are constructed of chemical-resistant, non-conductive modular panels and feature composite-resin surface materials. This modular design allows for onsite assembly, and the ability to easily disassemble, move and reassemble the units at a later date. They can easily accommodate tall apparatus, distillation processes, roll-in reactors, or long-integrated instrumentation systems. Custom sizes and designs can be built to exact specifications. — *Hemco, Independence, Mo.*
www.unimaxfumehoods.com

Laboratory cooler combines low price, high cooling power

The HTS-PS1 (photo) is a low-cost, compact cooling system that is designed for laboratory use. Typical applications include the removal of process heat or for temperature control for pipetting elements and bioreactors. The air-water cooler does not include an active refrigeration unit; instead, it uses a circulating cycle of cooling water in the form of a heat exchanger. Since there is no compressor, the device requires no maintenance, says the company, and it is quiet and easy to install. The circulating pump has a pumped capacity of up to 8 L/min, and a pressure output of 0.2 bar. The HTS-PS1 can be operated over a temperature range from 5 to 80°C. — *Hüber Kältemaschinenbau, Offenberg, Germany*
www.huber-online.com

Filter dryer has advanced data-logging capabilities

The GFD bench-top Nutsche filter dryer (photo) overcomes challenges with commonly used methods of Büchner filtration and over drying, says the manufacturer. For instance, the new GFD supports laboratory process development, combining filtration, solids isolation, cake washing and vacuum drying in one step. The final product is fully recovered through a removable filtration basket. With its latest advances in data logging, accurate control of agitator speed and recipe input, the GFD can run autonomously (without human intervention), says the company. Data can be saved and exported for futher analysis and repeatability studies. Designed with advanced ergonomics in mind, the GFD can be integrated into fume hoods but still maintain good process visibility, batch homogeneity and reduced product exposure. — *Powder Systems Ltd., Boise, Idaho*
www.powdersystems.com

Laboratory pH sensor family serves many applications

Sensorex

This company's laboratory pH sensors (photo) are designed for basic, advanced and research-grade applications. They offer a variety of customizable features that can help users to eliminate overspending on overly sophisticated sensors, and minimize frequent sensor replacement in challenging process environments. All pH sensors provide accurate, reliable measurements across full pH ranges (0–14), says the manufacturer. The company offers an interactive sensor-selection tool on its website. — *Sensorex, Garden Grove, Calif.*
www.sensorex.com

Laboratory-scale hot plates withstand aggressive media

TorreyPines Scientific

The EchoTherm Model H270 Programmable Stirring Hot Plate (photo) is designed to be purged using an inert gas through a fitting on the rear of the chassis. Purging provides a positive pressure inside the unit to prevent corrosive gases from entering the chassis and attacking the electronics of the stirring mechanism. These units feature ten-program memory with ten steps per program, temperature ramping, RS-242 I/O port, membrane keyboard and full-function liquid-crystal display (where all parameters are continuously visible). Heater tops are 8-in. square, solid ceramic with 600 W of power. Temperatures can be set to 450°C, are controlled by PID software, and are accurate to ±1°C and ±1°F, says the company.The units are supplied with a 6-in. Teflon immersion probe for controlling solution temperatures directly. — *TorreyPines Scientific, Carlsbad, Calif.*
www.torreypinesscientific.com

Software manages laboratory data and information

The intuitive LabHQ LIMS laboratory information-management system software is designed to support many information and quality-control activities in the laboratory. It was designed with input from a network of regulatory, quality and laboratory professionals. The software capabilities ensure data integrity for regulatory compliance, increasing operational and testing efficiency and reducing costs, says the company, and it offers an intuitive user interface. — *Broughton Software, Skipton, U.K.*
www.broughtonsoftware.com

Controllers manage bioculture and fermentation operations

ILS Automation

Designed as a drop-in replacement system for benchtop and pilot-scale reactors, the AFC bioreactor controllers feature a reliable, dedicated and open process control system. The AFC 928 Dual Bioreactor Controller (photo) uses micropumps instead of syringe pumps for very-low flow applications, providing precise control down to 0.05 mL/h, says the company. The system can be equipped with a variety of probes to measure pH, pCO_2, redox, cell density and more. — *ILS Automation, Inc., Warrenville, Ill.*
www.ils-automation.com

High-temperature bench oven reaches 1,000°F

The Grieve Corp.

The No. 1017 (photo) is a high-temperature bench oven that features 5-in. insulated walls, stainless steel exterior, Type 304 stainless steel interior, integral oven stand, and an 8-by-10-in., double-pane Pyrex/Vycor viewing window. Incoloy-sheathed tubular elements heat the oven chamber, while a recirculating blower provides airflow. — *The Grieve Corp., Round Lake, Ill.*
www.grievecorp.com ■

Suzanne Shelley

New Products

A portable gas monitor with an extremely long service life

The BW Clip4 (photo) is a new four-gas, portable monitor that can operate continuously for two years without the need to change sensors or charge batteries. BW Clip4 monitors significantly reduce maintenance costs associated with fleets of portable gas detectors by eliminating repair work and the need to stock additional sensors and spare units. Because it is always on, the BW Clip4 helps drive safety compliance by assuring that workers wearing the device are protected. Using non-dispersive infrared (NDIR) technology, the BW Clip4 reportedly consumes 1,000 times less battery power than a catalytic bead (pellistor) sensor, the traditional technology used to detect flammable gases in a portable device. Other features include the following: simultaneous monitoring of H_2S, CO, O_2 and combustibles; realtime display for instant gas readings, even in non-alarm conditions; and internal test functions that alert users when the unit should be replaced. — *Honeywell Analytics, Inc., Lincolnshire, Ill.*
www.honeywellanalytics.com

New chemical solution for dust suppression

Sentinel dust suppressant (photo) is a proprietary chemical that is designed to adhere the finest silica particles to larger particles to prevent the fines from becoming airborne. The chemical is sprayed onto sand grains and adheres to the small dust particles, effectively trapping them. Silica dust inhalation can be hazardous to the health of workers, and recent OSHA ruling has limited the permissible exposure limit (PEL) for respirable silica dust in order to have a safer work environment. This liquid dust-control agent is effective on sands of all mesh size, including 100-mesh sand. The mobility of the application system allows it to be applied at any site without impacting normal operations, and the robustness of the chemical helps it maintain its performance after multiple transfer points, says the manufacturer. — *Hexion Inc., Columbus, Ohio*
www.hexion.com

Extremely long submersible canned-motor pumps

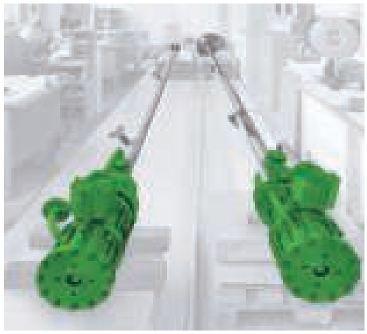
As a replacement for conventional submersible pumps, this company supplied two eight-stage, sealless canned-motor pumps of the TCAM 30/4+4 Series to a Swiss fine-chemicals company as an alternative to conventionally sealed pumps. The supplied submersible pumps (photo) are the longest pumps this company has ever produced, with an immersion depth of more than 15 m, and a pump shaft of only 1 m. The submersible pumps, in tandem design, convey the medium (ammonia) at a temperature of –33°C. The delivery head is 260 m at a flowrate of 12 m³/h. The pump units are designed for a nominal pressure of 40 bars and are suitable for operation with frequency converters (30–60 Hz). — *Hermetic-Pumpen GmbH, Gundelfingen, Germany*
www.hermetic-pumpen.com

This vibrating-fork level detector has wired HART connectivity

Rosemount 2140 (photo) is said to be the world's first wired HART vibrating-fork level detector. The Rosemount 2140 detects level in applications with high temperatures and harsh conditions that are unsuitable for other level-monitoring devices. It is easy to install and maintain, as there are no moving parts. The device is virtually unaffected by flow, bubbles, turbulence, foam, vibration, sediments content, coating, liquid properties and product variations, according to the manufacturer. It can be used to monitor not only liquids, but also liquid-to-sand interfaces, which enables the detection of buildup of sand or sludge deposits in a tank. For safety-critical applications, a dedicated version of the Rosemount 2140 certified to IEC61508 is available. For installations within safety instrumented systems (SIS), a fully integrated remote proof-testing capability eliminates the need to access the top of the vessel for extracting the device from the process. This saves time and increases process availability, worker safety and efficiency. — *Emerson Automation Solutions, St. Louis, Mo.*
www.emerson.com

Honeywell Analytics

Hexion



Hermetic-Pumpen

Emerson Automation Solutions

Prüftechnik Dieter Busch

Firmware adds capabilities to this shaft-alignment system

The Rotalign touch (photo) is a cloud-based shaft-alignment system that combines precision measurement with mobile connectivity. The latest free firmware release for the system — version 1.2 — now adds shaft-application capabilities. Cardan shaft alignment with specially designed brackets and a patented measuring method allows Cardan shafts to be aligned without removing the shaft, which significantly reduces the alignment time, effort and cost, says the company. Vertical machine measurement with Rotalign touch is now as easy as horizontal alignment, thanks to vertiSweep, the new continuous vertical-measurement mode: just rotate the shaft to measure flange-mounted vertical machines. Soft-foot diagnostics assist the user in identifying the possible causes of machine soft foot. The new Move Simulator capability enables the shim values to be predefined in advance of the physical movement of the machine. — *Prüftechnik Dieter Busch AG, Ismaning, Germany*
www.pruftechnik.com

Contact-free pump operation minimizes contamination

Gardner Denver Nash

The Dry-Pro line of dry vacuum pumps (photo) feature contact-free operation that requires no lubrication in the pumping chamber, minimizing process contamination and pollution caused by the pump operation. The Dry-Pro

line offers dry-screw vacuum-pump designs with fixed- or variable-pitch screw rotors. The pumps achieve an ultimate vacuum of .0015 in. Hg, and can operate at any pressure between end vacuum and atmospheric pressure. The pumps' design offers high vapor and liquid tolerances and can handle corrosives, organics, inorganics and solvents because of its oil-free, non-contacting screw design. In this design, the shafts and screws are one solid piece, which eliminates corrosion between the screw rotor and shaft that can occur in other pump designs, says the company. A low rotational speed avoids noise and vibration. — *Gardner Denver Nash, Bentleyville, Pa.*
www.gdnash.com

Monitor reformer-tube temperatures in realtime

Ametek Land

The near-infrared borescope NIR-B 3XR (photo) delivers continuous, high-accuracy reformer-tube-wall temperature (TWT) measurement, furnace optimization and monitoring, giving operators the ability to measure temperature point data and to store this data for future analysis. Operating with a wide-angle field of view (90 deg) and a high-resolution image, the NIR-B 3XR allows multiple reformer tubes to be imaged and measured simultaneously. That capability is critical to extending asset life and maximizing efficiency, as a –10°C measurement error over time can result in either 1% lost productivity, while a +10°C error can result in a 25% reduction in tube life. The NIR-B 3XR's advanced digital-communications capabilities mean that both image and data can be viewed in realtime from the safety of the control room. During startup, burners that are not operating correctly can be quickly identified and the effect of impinging flames can be seen, helping to optimize performance and reduce downtime. — *Ametek Land, Dronfield, U.K.*
www.landinst.com

Faster tank cleaning with lower water consumption

Bete

Orbitor Eco fast-cycle impingement cleaners (photo) are an alternative to spray balls for cleaning tanks and storage vessels. Rather than being geared for maximum power, Orbitor Eco devices are instead configured for maximum speed and water efficiency. These new machines can complete a cleaning cycle in under two minutes with flowrates as low as 45 L/min. When compared with spray balls, Orbitor Eco products operate at a similar pressure (2–3 bars), while offering a larger cleaning range (up to 10-m diameter), as much as 95% reduction in water consumption per cycle and a shorter cleaning-cycle time. With the availability of universal fittings, connectors, a range of threads and where required, adaptors, it is likely that in many cases, existing tanks, pumps and pipework will not need to be changed significantly for cleaning with Orbitor Eco devices. — *Bete Ltd., Lewes, U.K.*
www.spray-nozzle.co.uk

CUT Membrane Technology

BinMaster

Tubular membrane modules for recycling pickling acids

With cross-flow microfiltration, suspended particles can be removed from pickling acid effectively. Due to their high resistance against acids, caustics and abrasive metal particles, the T-CUT tubular modules (photo) are particularly suitable for this application. The symmetric tubular membranes are constructed from polypropylene (PP), offering resistance against abrasion, as well as mechanical and chemical stability. Microfiltration of pickling acids enables the contaminated liquid to be concentrated to a factor of up to five, which means a reduction of waste volume by the same amount. The remaining concentrate contains up to 35–40% solids. T-CUT PP modules ensure a stable permeate flux of about 80 L/(m^2·h). The filtration performance is maintained by backflushing the symmetric membranes for a few seconds every 30 min. — *CUT Membrane Technology GmbH, Erkrathm Germany*

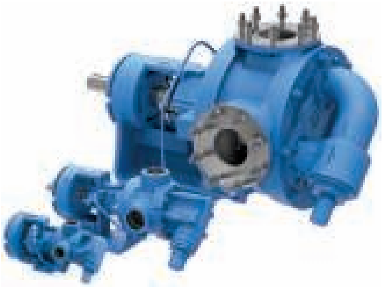
www.burkert.com/cut

A powerful radar level sensor for powders and bulk solids

The NCR-80 non-contact radar level sensor (photo) for powders and bulk solids features an 80-GHz frequency focused in a narrow 4-deg beam angle, enabling precise aiming to avoid the flow stream, internal structure or sidewall buildup. This ensures reliable performance at measurement ranges up to 393 ft and accuracy within 0.2 in. The NCR-80 is resistant to interference, and its firmware constantly tracks echoes and automatically eliminates false echoes for reliable performance. The NCR-80 is suitable for continuous, single-point level measurement in tall and narrow vessels where there is excessive noise or dust. Mounting the instrument is simple, due to the availability of 0- and 30-deg mounting plates for slanted roofs and 10- and 8-deg swiveling holders with directional aiming. A variety of flange sizes and adapter flanges are available. — *BinMaster, Lincoln, Neb.*

www.binmaster.com

New models added to this series of seal pumps



Viking Pump

This company has added four new sizes to its existing series of universal-seal pumps (photo), bringing the offering to a total of 16 different sizes, with available flows up to 364 m^3/h. This includes the addition of a smaller-sized pump for flows of less than 2 m^3/h. These heavy-duty, foot-mounted pumps are designed for a broad range of applications that require continuous operation at pressures up to 200 psi. As a whole, the models in this series can be applied to both viscous and non-viscous liquids, and are capable of operating under suction lift conditions. Seal options include packing, single component seals, cartridge lip seals and cartridge single- and double-mechanical seals. Various seal flush plans are also available. Different models are constructed of various materials, including cast iron, ductile iron, carbon steel or stainless steel with optional coatings and treatments to satisfy specific application needs. — *Viking Pump Inc., Cedar Falls, Iowa*
www.vikingpump.com

This distributor box makes connecting actuators easy

Phoenix Contact

With the universal M12 distributor boxes (photo), actuator connectors (such as those for solenoid valves) can be connected quickly and easily. Thanks to the full wiring of the M12 slots, both the switching wires, as well as the PE connection of valve connectors, are safely and easily connected to controllers and relays in the central control cabinet. The wire cross-sections of the permanently connected master cables (1.0 mm^2 for the supply wires and 0.5 mm^2 for the signal wires) are sufficiently large and have low cable resistances. If even larger wire cross-sections are required, these can be flexibly connected to sensor/actuator boxes with plug-in screw connections or spring-cage connections. LED status indicators, as well as the M12 Speedcon fast-locking technology (which reduces installation time by up to 90%) can also be added to the products. — *Phoenix Contact, Blomberg, Germany*
www.phoenixcontact.com

WTA Vogtland

ZOOK USA

These hybrid membrane modules offer many advantages

The new Submerged Membrane Module, dubbed H2L (photo), is this company's second-generation submerged membrane module for filtration applications in water and wastewater-treatment applications. H2L combines the advantages of two existing submerged module concepts, such as back-washability and high-packing density (hollow fibers), easy pre-treatment and good hydraulic behavior (flat-sheet). In addition, the multi-layer design of the membrane pockets, called Safe Guard Technology, ensures a safe rejection of bacteria and solids, even if the membrane layer suffers damage. The product is especially suitable for limited tank height and areas. The design concept of H2L is modularly built from the so-called USBs (Ultrafiltration Single Blocks), which are available in different sizes. Based on this concept, H2L is available in 64 different standard sizes ranging from 20 to 500 m^2 of membrane surface area. — *WTA Vogtland GmbH, Plauen, Germany*

www.wta-vogtland.de

Explosion protection for plastic extrusion applications

The EBP Series of explosion burst plugs (photo) are used to protect plastic extrusion equipment from overpressurization. The EBP Series' welded design provides a flush attachment, preventing potential product buildup. Stronger welded joints make EBP devices more resistant to increased temperatures, eliminating spurious bursts and product contamination. Joint failure is avoided during increased temperatures and pressure cycling. The welded design also removes material creep ensuring burst repeatability. The burst tolerance is ±10%, and all units are leak-tested and thread-verified using an optical comparator, and are ultrasonically cleaned prior to shipment. — *ZOOK USA, Chagrin Falls, Ohio*

www.zookdisk.com

Software add-on enables apps that integrate with CAD

This company has updated its LiveLink for SolidWorks products. As an add-on to the company's Multiphysics software, LiveLink for SolidWorks allows a computer-aided design (CAD) model to be synchronized between the two software packages. The latest version of LiveLink for SolidWorks allows easy access for launching and running simulation apps that can be used in synchronicity with SolidWorks software. Simulation specialists and analysts can now build apps with the Application Builder to enable users, such as design engineers, to analyze and modify a geometry from SolidWorks software right from the tailor made interface of the app. — *Comsol, Inc., Burlington, Mass.*

www.comsol.com

Level transmitter series newly launched in North America

K-TEK LMT Series magnetostrictive level transmitters have been launched in the North American

market. By adopting a two-wire common transmitter design combined with advanced signal processing, the LMT Series delivers reliable measurements with an integrated setup menu, advanced diagnostics with waveform display and signal conditioning. The first phase of the LMT Series comes with 4–20-mA HART output, and will be available with Foundation Fieldbus and Profibus PA later in 2017. LMT devices are available as an insertion-style "wetted" transmitter (LMT100) with probe lengths up to 22.86 m (75 ft) in length, or as an externally mounted, non-intrusive design (LMT200) for use with the KM26 magnetic level gage or with any other float and level chamber. LMT200 transmitters can be easily changed from top to bottom mount or from left-of-chamber orientation to right with no modification of equipment required. — *ABB Measurement & Analytics, Zurich, Switzerland*
www.abb.com/measurement

Submersible pressure sensors with many options

This company has introduced two high-performance submersible pressure sensors with a slimline design (photo). The model LW-1 is suitable for level monitoring of water and wastewater. The model LF-1 features long-lasting resistance within all common oils and fuels. Both submersible pressure sensors are, with their slimline case (22-mm dia.), suitable for use within pipes. Thanks to a newly developed sealing concept, special cable and further options, such as Ex and overvoltage protection during lightning strikes, the instruments work reliably even under harsh conditions. The new sensors are available with a variety of output signals. The LF-1 features optional temperature output for density compensation and temperature monitoring. — *WIKA Alexander Wiegand SE & Co. KG, Klingenberg, Germany*
www.wika.com

Mary Page Bailey and Gerald Ondrey

WIKA Alexander Wiegand

Fermentation

Department Editor: Scott Jenkins

For intermediate and specialty chemicals, the incorporation of biotechnology-based processes has become a viable option for the chemical process industries (CPI). This one-page reference discusses some of the benefits and challenges of fermentation-based processes.

Fermentation advantages

Among the potential advantages of fermentation processes over conventional processes are the following:

Improved selectivity. Bioengineering techniques generally allow the elimination of byproducts from the outset, by designing a microorganism to carry out the fermentation so that byproducts are not produced.

Reduced costs. Fermentation can dramatically reduce the number of process steps, as well as operational costs. Because the single unit operation of fermentation can replace multiple unit operations in conventional chemical processes, the cost per ton may be significantly lower (sometimes 20–40% lower) for bio-based process technologies. Also, capital equipment for fermentation-based processes may be less expensive because fermentation runs at near-ambient temperature and pressure and near-neutral pH, compared to more challenging conditions often required in a conventional chemical process. Reduced byproducts can lower downstream processing costs.

Fewer safety risks. With fermentation, complex chemistry can be catalyzed under mild, low-energy conditions, contrary to many industrial chemical processes. This can reduce some risks associated with high-pressure and high-temperature processes, and possibly eliminate the use of more dangerous chemicals.

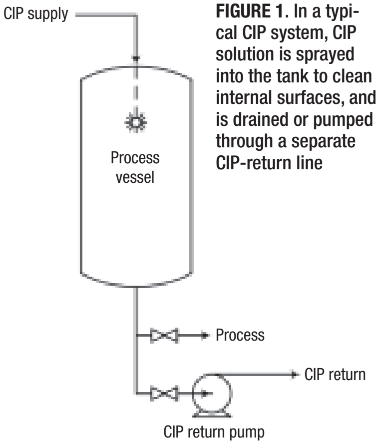


FIGURE 1. In a typical CIP system, CIP solution is sprayed into the tank to clean internal surfaces, and is drained or pumped through a separate CIP-return line

Sustainability. Conventional chemical processes usually start from nonrenewable resources (petroleum, natural gas or coal), while fermentation processes typically convert plant residues (biomass) or other renewable resources into the same product. This makes fermentation processes generally more sustainable.

Fermentation challenges

Fermentation processes carry unique challenges, including the following:

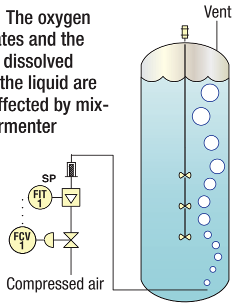
Removing water efficiently. Fermentation processes operate in aqueous environments. Effective handling and purification of aqueous streams may dictate specialized unit operations. Key concerns include energy-efficient techniques to remove water and the ability to recycle and reuse water.

Understanding impurities. Fermentation feedstocks are often carbohydrates, which can lead to product-quality issues, such as color and odor. If present in products, the color- and odor-causing compounds must be separated. Operators of fermentation processes must be familiar with carbohydrate chemistry, as well as protein and amino acid chemistries, to understand possible impurities.

Managing feedstock variability. Techniques for managing feedstock variations are different for bio-based processes than for conventional processes, and may include feedstock testing (to determine attributes), collaboration with feedstock suppliers to optimize consistency versus cost, rethinking the design of microorganisms to efficiently handle greater variation in feedstock properties, as well as adjusting operating parameters.

Maintaining temperature control. Insufficient cooling capacity can ruin fermentation due to temperature run-up, with consequences that can extend into downstream processing.

FIGURE 2. The oxygen transfer rates and the amount of dissolved oxygen in the liquid are strongly affected by mixing in a fermenter



This risk can be addressed through operating procedures that adjust process parameters to slow down the fermentation rate to maintain temperature control. Given the lower operating temperatures and aqueous streams, it may be necessary to account for the possibility of freezing in a fermentation plant.

Maintaining sterility. For fermentation processes, it is generally required to design, build and operate the process in a way that excludes viable foreign microbes. This is particularly critical in fermenters and associated systems, and can extend into downstream processing as well.

Preventing contamination. Preventing contaminants in fermentation is of paramount importance. This is accomplished with extensive clean-in-place (CIP) and sterilize-in-place (SIP) systems, and by using equipment that lends itself to being cleaned and sterilized (Figure 1). CIP systems remove foreign organisms and non-biological contaminants, such as grit, scale and organic matter. All may have an adverse effect on process performance.

Providing oxygen. Aerobic fermenters are essentially mass transfer devices that promote the transfer of oxygen from gas bubbles into the liquid medium where the microbes live (Figure 2). Oxygen transfer rate (OTR) can be a limiting factor in a fermentation process, so maximizing OTR is key to a successful fermenter design. ■

References

1. Miley, B. and others, Large-Scale Fermentation Systems, *Chem. Eng.*, November 2015, pp. 59–65.
2. Gregory, J. and Green, B., Mass Transfer in Fermentation Scaleup, *Chem. Eng.*, March 2014, pp. 44–48.
3. Weiss, S., Harnessing Biotechnology, *Chem. Eng.*, April 2016, pp. 38–43.

Sulfuric Acid Production from Sulfur

By Intratec Solutions

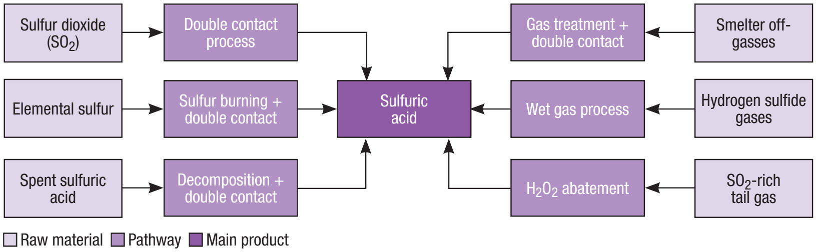


FIGURE 2. Several production pathways are available for sulfuric acid, a major industrial chemical

Sulfuric acid (H_2SO_4) is among the most important industrial chemicals, with large-scale uses in several industry sectors, such as basic chemicals, fertilizers, petroleum refining, metals, explosives, detergents and plastics. H_2SO_4 is broadly used in different concentrations and grades. Major applications include its use as a dehydrating agent, catalyst, reactant in chemical processes, solvent and absorbent.

The process

The following paragraphs describe a double-contact process for sulfuric acid production (Figure 1) in which elemental sulfur is the source of sulfur dioxide (SO_2). SO_2 can also be obtained from several sulfur-bearing raw materials, including spent H_2SO_4 and smelter off-gases.

Sulfur burning. Elemental sulfur (in molten form) and dried air are fed into a combustion furnace, in which the sulfur is burned to produce SO_2. The proportion of airflow relative to sulfur feedrate is controlled so that a sufficient concentration of oxygen is maintained in the process gas. This ensures proper conversion of SO_2 to SO_3 in the subsequent steps. This combustion furnace is equipped with a waste-heat boiler that cools down the reaction gas and generates high-pressure steam, which, in turn, is fed to a turbine for generating electricity. The cooled reaction product gas is directed to the SO_2 converter.

Double-contact process. In the SO_2 converter, SO_2 is oxidized to SO_3 in five catalyst beds within a single vertical converter. The gases from the third bed leave the reactor and are directed to an intermediate absorption step downstream, in which part of the SO_3 formed reacts with existing water in the recirculating H_2SO_4, forming more H_2SO_4. After this intermediate absorption step, the column off-gas is routed to the fourth and fifth beds for the last catalytic oxidation stages.

The oxidation product is sent to the final absorption step, which is analogous to the intermediate absorption. The concentrated H_2SO_4 is then fed to the intermediate absorption circuit. The final product (98.5 wt.% H_2SO_4) is discharged from the intermediate absorber circuit.

H_2SO_4 production pathways

The double-contact process is currently the most widely employed process for producing H_2SO_4. However, SO_2 starting material can be obtained from several sources, depending on local availability. Aside from elemental sulfur, spent H_2SO_4 and smelter off-gases are the main sources (Figure 2).

Economic performance

The process described here was considered in an economic assessment targeting the construction of a H_2SO_4 plant in the U.S. The analysis was based on a production capacity of 1.5 million metric ton/yr, and from economic data from the 4th quarter 2013. The estimated capital investment required would be about $160 million. This figure includes production units, storage installations, utilities facilities and auxiliary buildings, as well as working capital and additional capital requirements.

Due to the large scale of this plant, the raw material costs represent a significant portion of H_2SO_4 production cost. According to the aforementioned analysis, gross raw material costs were about $30 per ton of H_2SO_4 produced.

This column is based on "Sulfuric Acid Production from Sulfur via Double-Contact Process – Cost Analysis," a report published by Intratec. It can be found at: www.intratec.us/analysis/sulfuric-acid-production-cost. ■

Edited by Scott Jenkins

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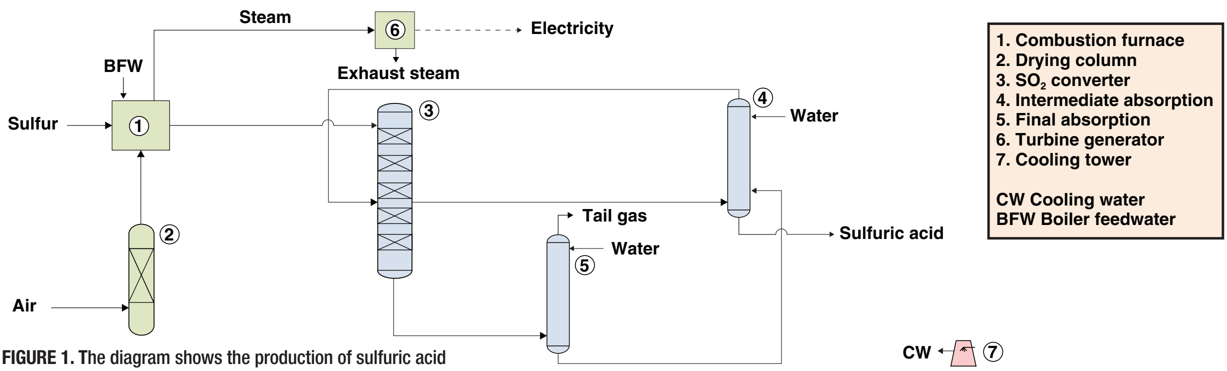

FIGURE 1. The diagram shows the production of sulfuric acid from elemental sulfur via double-contact process

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Control Engineering for Chemical Engineers

Chemical engineers who are aware of process control requirements and challenges are in a position to improve process designs

Lou Heavner
Emerson

IN BRIEF

Chemical engineers are ideal candidates for control engineering jobs. They understand processes and process design. However, many have never considered or studied process dynamics. Process engineers often provide the preliminary instrumentation and control requirements for new projects. Control engineering is just the next step. Control engineers try to identify and understand sources of process variability that can impact product quality, and then reduce the variability to mitigate its adverse economic effects.

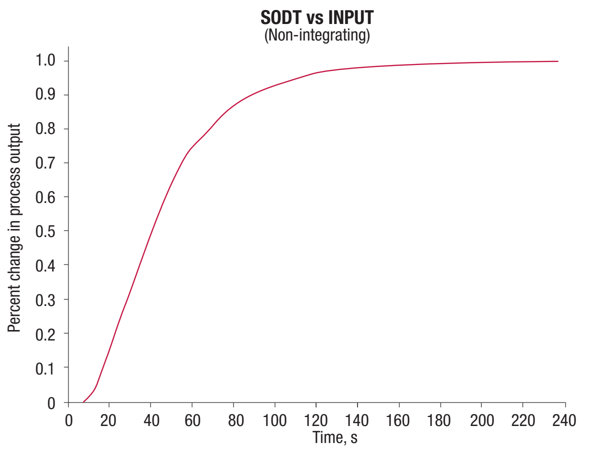


FIGURE 1. Responses to process inputs in self-regulating processes can take the form of first-order plus deadtime (FODT) or second-order plus deadtime (SODT)

There are many renowned chemical engineers who have made careers and reputations for themselves as control engineers, including the prolific author Greg Shinskey, the father of model-predictive advanced control, Charles Cutler, and academics like Thomas Edgar, Thomas McAvoy and Dale Seborg.

Even if a process engineer never becomes a control engineer, being aware of process control requirements and challenges will lead to better process designs. This article provides information to aid chemical engineers in their understanding of how to reduce process variability by better controlling processes.

A brief history of process control

Early process controllers were mechanical devices using pneumatics and hydraulics. Mechanical engineers were common in control engineering, especially since the most common final control element — the control valve — is inherently a mechanical device. Pneumatic controllers were gradually replaced with analog electronic systems. Electronics gave the advantage of faster communications between field instruments and controllers located in a central control room, as well as space savings and some improved features. They generally mimicked pneumatic controls, but electrical engineers began to displace mechanical engineers as control engineers. Relay systems were used to provide interlocks, logic control and sequence control.

Inevitably, analog single-loop controllers were replaced with multi-loop digital control systems — first, control computers and later, distributed control systems (DCS). Also at this time, programmable logic controllers (PLCs) began to displace systems of relays for logic and sequential control. Modern control systems are now leveraging the Internet, wireless technologies and bus technologies in new and effective ways. Field instruments and final control devices are becoming increasingly more "intelligent," providing for more non-control information than control information. Tools and user interfaces are becoming friendlier to use and more capable, offering tremendous productivity gains.

Electrical engineers continued to dominate the field of automation and control. But the additional computing capability in microprocessor- and computer-based systems led to an opportunity for more advanced control strategies. Chemical engineers, with their knowledge of process behavior and process requirements, have been working for years in the field of automation and control, and are often able to gain more value out of control systems than others with less process understanding might achieve.

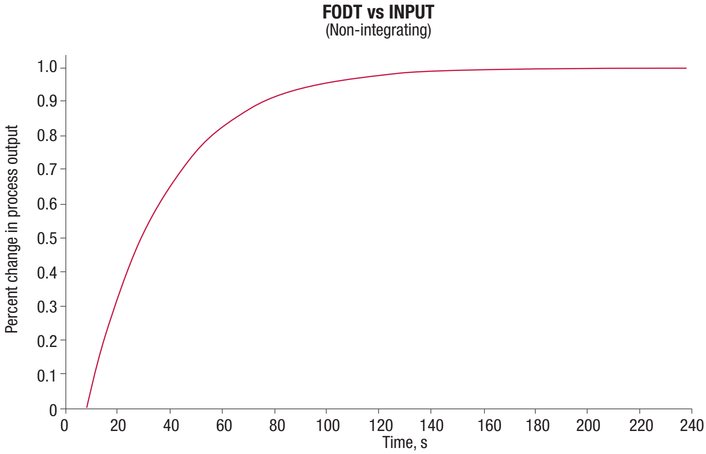


FIGURE 2. Typical first-order plus deadtime (FODT) responses are characterized by a rapid initial response to a process input, followed by slowing response as a new steady state is reached

Design basis and variability

Process engineering focuses on process design, and defines or assumes a design basis. That basis typically includes normal, maximum and minimum production rates, and the process engineer tries to optimize the process design, first in terms of capital cost and second in terms of operability. At this stage, project cost considerations and the availability of standard process equipment may require design compromises that lead to a process design with control challenges.

The design basis is a guideline, but operating conditions in a commissioned plant may change over time. Equipment (especially control valves) wear, feedstock qualities vary, catalysts age, processes are impacted by varying ambient conditions, and other sources of variability impact production. Market and regulatory conditions may also vary, shifting demand for certain products and byproducts or penalizing the production of waste products. The control system of the plant is intended to mitigate the effect of incoming sources of variability on product quality variability. As plants become increasingly complex, operators are faced with bigger challenges, and simply operating the process manually is no longer an option. A frequently cited analogy is the pilot in an advanced meta-stable jet dependent on advanced avionics.

Perhaps the best way to look at automation and control is as the business of managing process variability in real-time. One important thing to understand is that control systems are generally able to attenuate low-frequency ("slow") variability (on the order of seconds, minutes or more), but cannot attenuate high-frequency ("fast") variability (less than a few seconds).

Fortunately, process design can often be used to attenuate fast variability. Surge vessels can be used to attenuate highly variable flows between units, for example, reducing the disruption to the downstream unit from variability in the upstream unit.

Control engineers need to understand process dynamics, a topic area that is not always considered as part of the core of process design. It is convenient to think of process dynamics in terms of process inputs and process observations. Process inputs are material or energy flows, and they may be flows into, out of, or intermediate within a given process. As flows are changed, the process is affected, as seen by process observations. Process observations are measured as variables like temperatures, pressures, levels, compositions and flowrates.

As process designs are optimized for energy recovery and minimization of both capital cost and operating cost for a plant, they incorporate increasing integration between process streams. If variability is not controlled in a highly integrated process with a high degree of process interactions, there are more pathways for it to create quality issues. Therefore, it is increasingly important for design and control engineers to work together to ensure operability and strategize how to attenuate variability.

Control basics

Most process responses can be classified into self-regulating and non-self-regulating (or integrating). Self-regulating processes respond to a change in process

TUNING A PROPORTIONAL-INTEGRAL-DERIVATIVE (PID) LOOP

PID controllers are defined by the control algorithm, which generates an output based on the difference between setpoint and process variable (PV). That difference is called the error, and the most basic controller would be a proportional controller. The error is multiplied by a proportional gain and that result is the new output. The proportional gain may be an actual gain in terms of percent change of output per percent change of error or in terms of proportional band. Proportional band is the same as gain divided by 100, so the effect is the same, even if the units and value are different. When tuning a control system, it is important to know whether the proportional tuning parameter used in the controller being tuned is gain or proportional band.

When the error does not change, there is no change in output. This results in an offset for any load beyond the original load for which the controller was tuned. A home heating system might be set to control the temperature at 68°F. During a cold night, the output when the error is zero might be 70%. But during a sunny afternoon that is not as cold, the output would still be 70% at zero error. But since not as much heating is required, the temperature would rise above 68°F. This results in a permanent off-set.

Integral action overcomes the off-set by calculating the integral of error or persistence of the error. This action drives the controller error to zero by continuing to adjust the controller output after the proportional action is complete. (In reality, these two actions are working in tandem.) The integral of the error is multiplied by a gain that is actually in terms of time. Again, different controllers have defined the integral parameter in different ways. One is directly in time and the other is the inverse of time or repeats of the error per unit of time. They are functionally equivalent, but when calculating tuning parameters, the correct units must be used. Adding further complication, the time can be expressed in different units, although seconds or minutes are usually the design choice.

And finally, there is a derivative term that considers the rate of change of the error. It provides a "kick" to a process where the error is changing quickly and has a gain that is almost always in terms of time. However, again the units of time may be seconds or minutes. Derivative is not often required, but can be helpful in processes that can be modelled as multiple capacities or second order. Derivative action is sensitive to noise in the error, which magnifies the rate of change, even when the error isn't really changing. For that reason, derivative action is rarely used on noisy processes and if it is needed, then filtering of the PV is recommended. Since a setpoint change can look to the controller like an infinite rate of change and processes usually change more slowly, many controllers have an option to disable derivative action on setpoint changes and instead of multiplying the rate of change of the error, the rate of change of the PV is multiplied by the derivative term.

There are two steps to tuning a controller. First the process dynamics must be identified. This can be done with an open-loop or closed-loop step test. In open loop, the controller is put in manual mode and the output is stepped. The PV is observed and the process deadtime, gain, and time constants are estimated. Several steps should be made to identify any nonlinearity and to ensure the response is not being affected by an unmeasured disturbance. In closed loop, the controller is forced to oscillate in a fixed cycle by stepping the output, forcing it to oscillate with an amplitude that will be dependent on the process gain and step size. This can be achieved with a controller by zeroing the integral and derivative terms and adjusting the proportional gain until the cycle is repeating, or by using logic that switches the output when the cycling PV crosses the setpoint value.

The second step is calculating the tuning parameters. There are different guidelines proposed by different authors and even software that will calculate the tuning parameters for the tuner to achieve the desired response. One guideline that is wisely favored is the "lambda" tuning method. Lambda refers to the closed loop time constant in a controller response. The advantage of this kind of tuning is that the tuner is free to choose the speed of response or the aggressiveness of the controller tuning. There is a tradeoff in loop tuning. As noted earlier, faster response or more aggressive tuning may result in some overshoot or even cycling response that is undesirable and the loop could become completely unstable if there is any nonlinearity in the process. Therefore, robustness is the sacrifice for more aggressive control and lambda can be used to strike an optimal balance between robustness and aggressiveness.

input by settling into a new steady-state value. For example, if steam is increased to a heat exchanger, the material being heated will rise to a new temperature. Reponses often take the approximate form of first order plus deadtime (FODT) or second order plus deadtime (SODT) (Figures 1 and 2). In a heat exchanger, for example, when the steam valve is opened, more steam enters the heat exchanger. First, the steam pressure in the exchanger rises and heat transfers to the tubes and finally to the colder stream. The temperature of the cold stream takes some time before it begins to rise. Then it rises gradually and increases its rate of change until it approaches the new steady-state temperature, where the temperature rise begins to slow. The characteristic response is a SODT.

The steam flow began increasing as soon as the valve started moving. But if a controller was telling the valve to open, there might have been a short delay before the valve actually moved and the steam flow changed. The steam flow begins to increase quickly and begins to increase more slowly as the new steady-state flow is achieved. This is a typical FODT response.

Self-regulating control loops can be tuned for closed-loop control response to assure that the process observation (sometimes known as the process vari-

FIGURE 3. Integrating, or non-self-regulating process variables do not settle into a new steady-state value within allowable operating limits

able, or PV) is driven to and maintained at its target setpoint. The control response can be tuned for faster or slower response, but as the speed of response increases, so does the risk of overshoot or oscillation.

Different measures of performance have been developed with tuning rules to approximately achieve these objectives. Early performance objectives focused on minimizing error, square of the error, or absolute error over time. Tuning to achieve quarter-amplitude damping was often described in early control literature. Zeigler-Nichols tuning rules were proposed to achieve this kind of response. But this kind of aggressive tuning results in some cycling.

Recent thought in automation prefers to attenuate variability, and that includes closed-loop oscillation, so most loops today should be tuned for a first-order response, with the response time being defined according to process requirements. The fastest-responding loops are limited by the point of critical damping. However, where loops interact, one can be slowed relative to another to prevent the interacting loops from fighting with each other. Important time constants are the deadtime, which is the time before the process observation is observed to change, and a first-order time constant, which is the time it takes once the process begins moving to achieve approximately 63% of the way to the target setpoint. A first-order process normally takes about four time constants, plus the deadtime, to reach steady-state at the target setpoint.

Non-self-regulating process variables do not settle into a new steady-state value, at least not within allowable operating limits (Figure 3). Changing the rate of feed into a vessel will change the rate at which the level rises (or falls). In the absence of some kind of control, the level would continue to rise until the tank overflowed. Usually integrating process responses can be described as deadtime and integrating gain or ramp rate. Sometimes, there may be a lead or lag associated with the ramp rate, but this is not common, and when it occurs, it tends to be minimal.

Fortunately, controllers can also be tuned on integrating processes to achieve a first-order response. However, the response does not look exactly like the response of a self-regulating process. Following a setpoint change, the PV will move to the new setpoint and overshoot

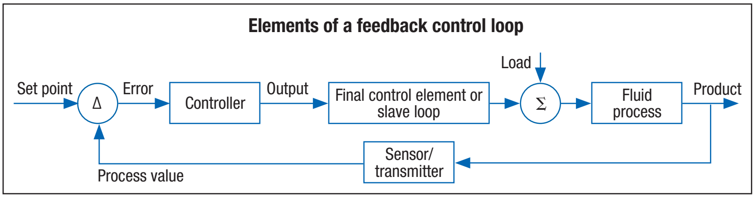


FIGURE 4. Most process control is accomplished by using a feedback control loop

slightly before turning around and settling back at the target value. Following a disturbance, the PV will deviate from the target setpoint until finally being arrested and returning to setpoint. Deadtime is the same as for a self-regulating process. There is no open-loop time constant by definition. However, the closed-loop time constant for an integrating process is defined as the time it takes to first cross the target setpoint following a setpoint change or the arrest time for a disturbance. An integrating process normally takes about six time constants, plus the deadtime, to reach steady-state at the target setpoint following either a setpoint change or a load disturbance.

Feedback controllers

Process control usually takes the form of a feedback controller (Figure 4). Some process inputs can be manipulated in order to drive important process observations to targets or setpoints. Other process observations may not be controlled to a target setpoint, but they are not allowed to exceed upper or lower constraint limits. A control-loop includes a measurement of the process observation to be controlled (the PV), a final control element (usually a control valve) that varies the process flow to be manipulated and a controller that makes a move based on where the process observation is relative to its setpoint.

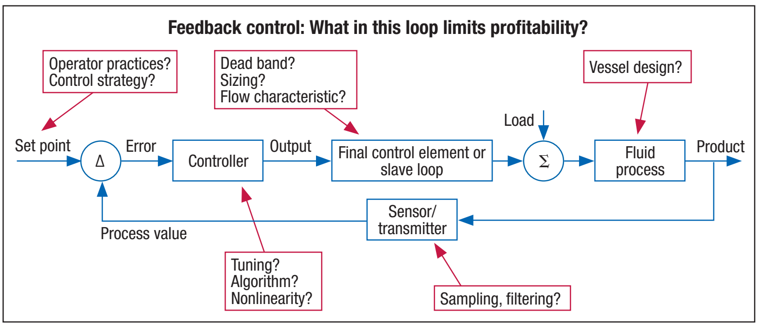
The workhorse controller in the process industry remains the PID (proportional-integral-derivative) controller. It is robust and a good fit for the job as long as the process response is not excessively nonlinear or characterized by a dominant deadtime dynamic. Proportional, integral and derivative are the actions the controller can apply to drive the PV to setpoint. Every controller manufacturer may employ a slightly different form, structure and options, but the functionality and results are the same. The proportional, integral and derivative parameters can be adjusted by the control engineer to provide the best controller response. In order to properly tune a control loop, it is necessary to understand the things that influence loop performance and process profitability (Figure 5).

Often, process inputs can impact more than one important process observation. If the heat exchanger was the reboiler of a distillation column, increasing the steam could affect the levels in the base of the column and the reflux accumulator and compositions at the top and bottom of the column. It might also affect the column pressure and differential pressure, and will affect temperatures up and down the column. Similarly, a process observation might be affected by more than one process input. The distillate composition may be affected by the steam flow to the reboiler, the reflux flow, the feed flow, the product flows and other process inputs. An interactive process requires that the controls be designed to minimize the detrimental impact of multivariable interaction, where two or more loops could fight with each other. One way to do this is with a decoupling strategy, which is something easily understood by process engineers. Feed-forward control and sometimes ratio-control strategies are used to decouple process interactions. The interacting process inputs may be controlled or could be "wild" disturbances. Another way to decouple loop interactions is by tuning one loop for a relatively faster response and the other for a relatively slower response. This technique is very effective and is naturally applied when tuning cascade loops.

Advanced process control

There are different definitions of advanced process control (APC). Some people consider ratio control and override control to be advanced control. Control strategies that use feed-forward, override-control, cascade and

FIGURE 5. Several aspects of a process-control loop can influence performance and profitability



ratio loops and other complexities are often referred to as advanced regulatory control (ARC). Another type of controller is the multivariable, model-predictive controller (MPC). The response models of all process outputs to changes in any process inputs are modelled and incorporated into the controller.

The controller attempts to maintain the controlled variables at targets and constraint variables within limits while minimizing the moves of process inputs. It does this with an algorithm that controls a prediction sometime in the future rather than the current process value. It is an ideal approach for interactive problems, since instead of decoupling the interactions, it coordinates the moves to compensate for or accommodate the known interactions. Those interactions are identified in the embedded models. It is also the only truly effective means of handling deadtime-dominant processes because the deadtime is inherently defined in the controller models.

APC has been widely applied in the petroleum refining industry and is gaining greater acceptance in other industries. It is an excellent platform for constraint optimization. Many process-control problems benefit from constraint optimization. Optimization objectives, such as maximizing production and yield, and minimizing give-away and energy consumption are examples of where constraint optimization can generate substantial benefits over single-loop control. Maximizing or minimizing some variables can drive the process to constraint limits and the models allow for tight control at constraint limits without violating them (Figure 6).

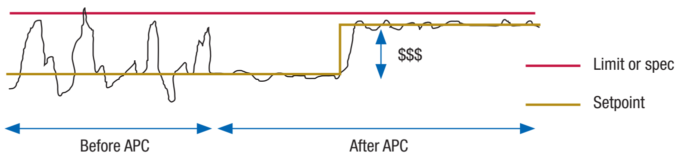


FIGURE 6. Advanced process control (APC) techniques help allow processes to operate closer to the limit through constraint optimization

Batch process control

Up to this point, the discussion has covered continuous processing. Continuous processes dominate the chemical process industries (CPI), but some sectors of the CPI, including pharmaceuti-

GLOSSARY OF CONTROL TERMINOLOGY

APC ***Advanced process control.*** A general term for types of controls more elaborate than the basic loops. MPC is a type of APC, and MPC is often used interchangeably with APC. Other examples of APC include fuzzy logic and expert systems

ARC ***Advanced regulatory control.*** A complex control strategy often involving more than one PID controller (examples include cascade control, ratio control, feed-forward control, override control and inferential control)

CV ***Control variable.*** A process observation that has a setpoint that may be provided by the operator or by a supervisory controller

DCS ***Distributed control system.*** A digital process control platform in which various controllers are distributed throughout the system

DV ***Disturbance variable.*** Measured process inputs that are not manipulated by the controller (also known as feed-forward inputs)

HC ***Hand control.*** Used to indicate a manually positioned valve

LV ***Limit variable.*** A constraint variable or process observation without a setpoint

MIMO ***Multi-input, multi-output.*** A term describing a multivariable controller

MISO ***Multi-input, single output.*** A term describing a multivariable controller with one output

MPC ***(1) Model predictive controller.*** A controller that controls future error rather than current error. To do this, it incorporates process response models that describe the dynamic behavior of process observations (CVs and LVs) to changes in process inputs (MVs and DVs). This allows the controller to plan moves in the future to provide control over a future time interval. This technology is helpful with processes that have long process delays or a high degree of interaction between multiple process inputs and outputs. It is the ideal platform for constraint optimization
(2) Multivariable process control. Means controlling more than one measurement or variable at a time from the same calculation. Since most model-predictive controllers are also multivariable controllers, the definitions are often used interchangeably

MV ***Manipulated Variable.*** A process input that is an output of a controller

PID ***Proportional, integral, derivative.*** The name used for the most common control loop algorithm seen in the process industries. PID controllers are SISO feedback controllers

PLC ***Programmable logic controller.*** Computer for industrial control

PV ***Process value.*** The term commonly used for the CV of a PID control loop

SIMO ***Single-input, multi-output***. A term describing an uncommon multivariable controller with one process output (an example would be split-range control)

SISO ***Single-input, single-output controller.*** A term describing typical PID controller or any controller with one input and one output

SP ***Set point.*** The target value for the control variable

TSS ***Time to steady state.*** The time required for a self-regulating process to come to a new stable steady state after a change to a process input

cals and specialty chemicals, rely heavily on batch processing. Some engineers muse that all processes are batch processes, but some batches are longer than others. A batch control engineer might suggest that a batch process is just a continuous process that never gets the chance to reach steady-state. Both are valid points of view. Designing batch process sequences and recipes fall right in the comfort zone for chemical engineers. But the more interesting part of batch control is not defining the normal sequence of steps. Rather, it is defining what should happen when an abnormal event occurs. Can a batch be "saved" following an upset or must it be scrapped? What is required to rework a batch that suffered an abnormal upset? Thinking through the possible problems that could disrupt a batch process and defining safe sequences to abort or recover a batch are classic chemical engineering exercises.

Another opportunity for batch optimization involves trying to minimize transition times between steps. This can be done with equipment selection, but also with logic in the batch sequence. Ramp rates and dwell times can be minimized to the extent practical without impacting batch quality. There is a standard defined (ANSI/ISA S88) for batch process control that standardizes the concepts of control, equipment and unit modules in a batch process.

And batch processes are often designed to make a variety of products or product grades. Furthermore, there may be multiple trains of equipment with some common process equipment or utilities. These plants may involve special recipes. Recently in batch control, the focus has been on managing multiple recipes and optimizing equipment selection for maximum or optimum production.

Because product flaws in the pharmaceutical industry can be devastating, traceability is a major concern. This includes traceability of the materials consumed in the production of pharmaceuticals, and traceability of the equipment and processes used to produce the pharmaceuticals. Regulatory involvement is high, and validation is an integral part of pharmaceutical processes. This requires more data collection and more rigorous adherence to management of change (MOC) procedures than most other processes, whether batch or continuous.

Process safety in control

Another area of process control deals with safety instrumented systems (SIS). Up to this point, the discussion has centered on control requirements to keep the process running in the face of variability. Safety systems have a single function, which is to safely shut down a process if a catastrophe is imminent. Process engineers may be better prepared to consider process safety than most disciplines, at least with regard to the CPI. The general concept is to evaluate the risks, in terms of probability, and the magnitude of the consequences.

Layers of protection are defined and deployed to reduce the risk of a serious safety or environmental exposure. High-risk possibilities need to employ engineering solutions to reduce the risk. Some solutions will include process design, such as dikes around tanks and pressure-relief equipment. Controls will also be employed to reduce the risk, including safety interlocks. The requirement for high on-demand availability of the safety-protection systems leads to specialized safety systems with redundancy (including triple redundancy) and pro-active diagnostics to monitor the health of the safety systems. One of the first layers of protection is alarm management, although it is limited by the presence of the human element to respond to an alarm (for more on alarm management, see *Chem. Eng*. March 2016, pp. 50–60). Designing safety-instrumented control systems is a specialized area that is critical in managing the risk of hazards in the process. There is a growing trend to design safety systems to be integrated into — but still separate from — the basic control systems. Care is taken during design to ensure the integration does not create a vulnerability or common point of failure of the safety system function and reliability.

Along with this trend is the increasing use of diagnostics and capabilities of "smart" instruments and field devices to reduce the probability of failure on demand. This is a critical consideration for safety systems, because they may not be employed for long periods of time, if ever, but then must work when called upon to shut a process down safely.

Process data

A final area of process control where process engineers can have a significant impact is data management and analysis. Control systems have access to a great deal of data other than control data. Historization and archiving of process data enables process engineers to identify and prioritize continuous improvement opportunities and allows management to make more effective decisions regarding operation and future investment.

Business systems that manage maintenance processes, quality processes, planning processes and other work processes can be integrated with process control. This has been enabled by modern technology for networking, databases, operator interfaces and enterprise-management software all working together. While the nature of integration of these various systems requires more knowledge in computer programming, database administration and networking than chemical engineers might learn in their academic programs, the process management requirements require an understanding of the process plant and its economic sensitivities. Chemical engineers are likely to have a better understanding than most of the information required by company managers at both the local and corporate level in order to make best use of the data and systems in place. The increasing wealth and richness of data makes analysis of that data with evolving "big data" tools a real opportunity. Networking, data sharing, and collaboration between the plant and specialized resources located far away is the promise of the Industrial Internet of Things (IIOT).

Concluding remarks

Often the greatest knowledge gap for a chemical engineer who wants to become a process automation engineer is deep knowledge of instrument and control hardware. This is not an insurmountable problem, however, because vendors are happy to share the information you need. A good salesperson, perhaps contrary to popular opinion, can be a valuable and trusted advisor. The best salespeople know that exaggerating the benefits of one offering for immediate sale may win the order, but will lose the confidence and trust of the customer for future opportunities.

In most cases, vendors truly do want to recommend the most economical solution. To do that, they need to understand the process and control requirements and the expected life cycle of the unit where the offering will be deployed. They can recommend the best measurement technology or valve selection and help size the instrument as well. They can help evaluate the value and return of additional options or choices. So leverage their special knowledge and expertise. Often on a larger project, an engineering firm with its own subject-matter experts may help with selection and procurement, or selection may be defined by corporate guidelines or process licensing requirements.

In the final analysis, the control engineer is trying to identify and understand the sources of variability that can impact product quality, production throughput, yields, utility consumption and other economic impacts, and tries to design controls to attenuate the variability or move it to a part of the process where it has less economic impact. By simply reducing variability, it is possible to operate nearer to constraints and hence maximize the processing capability of the existing plant.

Chemical engineers who are interested in process control can find many resources to gain a deeper understanding in the further reading section. ■

Edited by Scott Jenkins

Further reading

1. Shinskey, F.G., "Process Control Systems: Application, Design and Tuning," 4th ed., McGraw Hill, 1996.
2. McMillan, G., "Handbook of Control Engineering," McGraw Hill, 1999.
3. Blevins, T. and Nixon, M., "Control Loop Foundation – Batch and Continuous Control," International Society for Automation (ISA), 2011.

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Eye Protection, Part 1

Beyond Basic Eye Safety

How to protect, preserve and enhance workers' safety

Wanda Sanchez-Miller
Honeywell Safety and Productivity Solutions

IN BRIEF

CHOOSE THE RIGHT PROTECTION

SELECTING LENSE TINT

LENS COATINGS

ENSURE PROPER FIT AND COMFORT

STYLE'S ROLE IN COMPLIANCE

ADDRESS VISION CORRECTION

FIGURE 1. Among all the different types of personal protection equipment used in the chemical process industries, safety eyewear is among the most prevalant

Safety eyewear (Figure 1) is among the most prevalent types of personal protective equipment (PPE) worn across the chemical process industries (CPI). It protects an individual's most valuable sense — vision — through which we gain up to 85% of our total knowledge. Due to the eyes' delicate construction and location, they are vulnerable to a wide array of hazards found in nearly every environment, from airborne particles and flying objects to chemicals and harmful radiation.

To help protect individuals' eyes at work, national and employer-based safety standards are in place that require the use of safety eyewear based on the hazards present. Specifically, the Occupational Safety and Health Administration (OSHA; Washington, D.C.; www.osha.gov) calls for employers to provide employees with proper eye protection wherever hazards to the eyes exist, and such eyewear must meet the American National Standards Institute's (ANSI; www.ansi.org) Z87.1-2015 standard for impact protection. Safety eyewear styles range from spectacles and goggles to sealed eyewear, each intended to provide a specified level of protection.

Despite comprehensive safety standards, recordable eye injuries continue to occur at an alarming rate of 2,000 per day in the U.S. alone [*1*], incurring a massive toll on affected individuals and employers alike. For individuals, eye injuries often result in short-term vision loss, permanent blindness or the loss of an eye, which can diminish quality of life and the capacity to earn a living. Furthermore, the cost to U.S. industry is staggering, estimated to exceed $300 million each year [*2*]. Most injuries are attributed to use of the wrong eye protection for the hazard — or the absence of safety eyewear altogether.

Most experts agree that up to 90% of eye injuries can be avoided through the proper use of safety eyewear [3]. It's easy to see that selecting the proper eye protection for the application is vital to worker safety. Lesser known factors, however, such as specialized lens tints, anti-fog coatings, proper fit and modern styling, all play major roles in compliance and eye safety. This article looks beyond basic eye protection to reveal the ways in which safety eyewear can be used to protect, preserve and enhance worker vision across the CPI.

Choose the right protection

The first step toward workplace eye safety is for the safety manager to conduct a thorough facility walk-through to assess the hazards faced by employees in each zone. Look for machinery, flying objects and airborne debris, and chemicals that could come in contact with the eyes. Review material safety data sheets (MSDS) for specific safety precautions, as well. Based on this information, determine the appropriate kind of eye protection required for each individual and for each task he or she conducts. Remember, OSHA calls for employers to provide eyewear that meets the ANSI Z87.1-2015 standard for impact protection; such eyewear is marked with "Z87" on every major component. For high-impact hazards, eyewear that meets military-grade ballistic protection, known as Military Velocity Sub-Zero, should be considered.

There are three basic styles of safety eyewear from which to choose (Figure 2). Plano eyewear looks like regular glasses and provides basic impact protection; sport-inspired wraparound styles afford the user increased coverage and peripheral protection. Safety goggles, which seal tightly to the face, are mandated for individuals in high-dust environments and for those exposed to hazardous chemicals. However, because they are sealed, goggles are prone to fogging, and some may feel clunky, heavy or uncomfortable.

Sealed eyewear is a relatively new and increasingly popular option for extreme environments. A hybrid between spectacles and goggles, sealed eyewear looks and fits like a spectacle and can offer protection similar to a goggle-type seal in a comfortable, secure, low-profile design. Recognized for its versatility, sealed eyewear is available in an array of lens tints and coatings, with reader options for magnification, as well as with optional head straps for a tighter seal and removable foam inserts that convert the eyewear to regular spectacles.

Selecting lens tints

While safety eyewear is designed primarily to protect the wearer from physical hazards, in many applications its lenses also serve to protect against other visible and invisible hazards. Optical radiation is an easily overlooked hazard — yet exposure to natural and manmade sources of radiation can cause short-term injuries such as photokeratitis, as well as long-term effects including cataracts and permanent blindness. From blocking blinding laser light to invisible ultraviolet (UV) and infrared (IR) rays, lens tints can provide the added protection workers require to stay safe and conduct their jobs effectively.

In outdoor environments, it is vital that workers' eyes be protected from the sun's damaging visible and invisible rays. In fact, long-term exposure to the sun's invisible UV light is a leading cause of cataracts and blindness. Employees who spend any time outside should be outfitted with eyewear that blocks more than 99% of UV rays. Look for safety lenses marked with a "U," which denotes ANSI-rated protection from both UVA and UVB spectrums.

Outdoors, workers are also exposed to direct sunlight and glare, visible optical radiation also commonly overlooked in safety audits. Overexposure to direct and reflected light causes headaches as well as eye fatigue, redness, dryness and irritation, all of which can undermine productivity. To combat natural light hazards, eyewear with standard gray, brown or mirrored lens tints offer suitable protection and may be selected based on user preference. In environments where glare from sunlight is reflected off surfaces such

FIGURE 2. Among the various styles for safety eyewear are the plano (top), which provides basic impact protection, and safety goggles (bottom), which seal tightly to the face for protection against hazardous chemicals

as water, sand, glass, sheet metal or concrete, look for lenses that are mirrored, polarized or darkly tinted and are marked with an "L" for effective glare reduction.

To support visual function in indoor applications with specialized lighting, unique dyes are incorporated into the polycarbonate lens material that absorb select wavelengths of radiant energy (light). Such lenses can manipulate light to reduce a spectral hazard or to provide distinctive filtration for specific viewing tasks. For instance, in operations where a high level of yellow light is present, specialized blue lenses counteract color distortion and help prevent eye fatigue. Vermilion (scarlet) lenses are useful in certain inspection operations where the color shift enhances contrast or highlights shadowing for better inspection results and increased productivity. While orange lenses effectively filter blue and violet light present with UV curing lamps, amber lenses are commonly used to aggregate reflected light for a brighter view in low-light environments. Deep cobalt lenses are valued by furnace workers for their ability to deliver excellent spectral performance while protecting from harmful IR rays.

Remember, many colored lenses affect the wearer's ability to identify colors correctly; selecting lenses with true color recognition is essential for traffic signal identification and other applications that rely on color coding.

Lens coatings

Lens coatings deliver anti-fog properties, anti-scratch properties, or a combination of the two. Together, such coatings prolong a clear, unobstructed view of the environment, improving worker safety. Furthermore, effective anti-fog and anti-scratch coatings extend lens life, adding longevity and value to your eyewear investment.

Anti-fogging. Lens fogging is a leading problem faced by workers wearing any type of safety eyewear — and it affects safety, productivity and compliance. Factors that cause fogging include the temperature variance between a worker's body heat and cooler outside air temperatures; the change in temperature when workers transition from warm indoor environments to cold outdoor surroundings; and perspiration caused by exertion. Given its direct association with both the worker and the environment, fogging is nearly impossible to avoid. How to prevent fogging is discussed in more detail in part 2, pp. 56–59.

Scratch resistance. A lens's ability to resist scratches is of utmost importance — especially in high-hazard environments like hot, dry, windy outdoor conditions where flying dust, sand, debris and fragments are most likely to make contact with lenses and cause scratching. Once scratched, lenses no longer afford the wearer a clear, uninterrupted or comfortable view of the workplace and hazards, and they should be replaced. To combat scratching, scuffing and degradation from a variety of chemicals — and to prolong safety lens life overall — look for eyewear with a proven, long-lasting, scratch-resistant hard coat.

Ensure proper fit and comfort

Easily overlooked, the comfortable fit of safety eyewear directly supports protection and compliance. When eyewear fits poorly, it slides or slips off the wearer or causes painful pressure points on the temples or nose bridge. If eye protection isn't in its proper place when an accident happens, the risk of injury to the eyes is significant.

Another result of ill-fitting eyewear is worker discomfort, distraction and frustration — all of which disrupt productivity and lead to the removal of eyewear to eliminate the hassle of making frequent adjustments. When eyewear is removed due to poor fit, workers face increased risk of injury, and employers risk fines for non-compliance.

Well-fitting safety eyewear should provide snug, gap-free coverage and all-day comfort. But beware: a style that fits one worker comfortably may prove uncomfortable for another. An increasingly diverse workforce is contributing to vast differences in the height, width and location of cheekbones, nose bridges and ears, as well as overall head size and shape.

To meet the needs of a variety of facial profiles, look for fit and comfort features designed – and proven – to deliver a custom fit. Padded or fingered nosepieces, for instance, ensure a secure grip, while cushioned or hinged temples allow a personalized fit behind the ear. Ratcheting temples allow workers to achieve a gap-free fit against the face to maximize protection. For the best chance of selecting a single style that is comfortable for most, look for manufacturers that invest in anthropomorphic research and design, and offer solutions proven to fit up to 85% of the workforce right out of the box.

Style's role in compliance

While protection is the most important attribute of safety eyewear, attractive styling directly supports consistent wear. Studies show that workers who are not comfortable with the style of their eyewear are more likely to remove it — even in the presence of hazards. Furthermore, when workers are allowed to select their own safety eyewear without proper guidance, they are likely to make their selection based on style over safety or fit, which can lead to serious performance problems.

Given the leading role style plays, look for modern, lightweight options such as wraparound frames, floating lenses or sophisticated metal frames. Many safety eyewear styles — including prescription frames — are fashioned after popular recreational and sport-inspired sunglass designs. The goal is to select safety eyewear that workers are willing to wear — even when a safety manager isn't looking. By offering eyewear that is best suited to workers' safety needs first followed closely by style, employers support a stronger culture of acceptance and compliance.

Address vision correction

A very important — and often overlooked — aspect of delivering a comprehensive safety eyewear program is vision correction. According to the Vision Council, 70% of workers require vision correction, and that number is on the rise with the growing population of Baby Boomers in the workforce. Furthermore, the Council estimates that uncorrected vision problems cost businesses more than $8 billion in lost productivity each year. When vision loss goes uncorrected, employers not only suffer from decreased productivity, but they put themselves and their employees at risk. When unable to see their work and surrounding hazards clearly, workers are more prone to experience a serious injury and individual companies can pay thousands, even millions, in costs.

A popular solution to delivering eye protection for individuals who require corrective lenses is over-the-glass (OTG) safety eyewear. However, because OTGs are worn over existing prescription frames, drawbacks abound, ranging from poor comfort and fit, to limited visibility and reduced peripheral view, to unattractive styling. As a result, workers are more likely to remove their OTGs and simply rely on their standard prescription lenses. But street wear is not rated for impact protection, so workers who forgo OTGs are exposed to the same level of risk as those not wearing any protective eyewear. Like goggles, OTGs that are large or heavy can feel uncomfortable, especially during long-term wear; look for lightweight, low-profile styles with adjustability features that allow for a customized fit. Finally, because OTGs require a worker to look through both the corrective lenses and the OTG lens, there is potential for optical distortion. Safety managers should check with workers wearing OTGs to rule out potential interference.

While OTGs are an excellent option for visitors and short-term use, the best option for protecting workers who require corrective lenses and all-day protection is prescription safety eyewear. Each pair is manufactured individually to meet the worker's specific vision needs and fit with a single, comfortable solution. And, like planos, prescription safety eyewear can feature optional side shields for added coverage.

Today, perscription safety eyewear is available in a multitude of styles to meet each individual's preferences and safety requirements. Prescription lenses are now available in sealed eyewear styles as well, delivering the comfort and fit benefits of spectacles while providing the increased protection of a goggle. When manufactured properly, prescription safety eyewear delivers fantastic results: an individual's vision is corrected, workers feel more comfortable in their eyewear, and as a result they are more likely to leave it on throughout the day, thus improving worker safety.

When it comes to protecting workers' vision, taking a comprehensive approach to safety eyewear is a winning strategy. By considering the various factors beyond basic impact and chemical protection, employers can deliver the safest solution as well as one that workers are most likely to put on — and leave on — all day. As a result, employers benefit from reduced recordable eye injuries and related costs, and a healthier, more productive and compliant workforce. There's no better time than now for CPI companies everywhere to bolster their commitment to safety, starting with their workers' eyes. ■

Edited by Gerald Ondrey

References

1. Centers for Disease Control and Prevention, The National Institute for Occupational Safety and Health (NIOSH), Eye Safety, Washington, D.C., www.cdc.gov/niosh/topics/eye/
2. Occupational Safety & Health Administration, (OSHA), Safety & Health Topics: Eye and Face Protection, Washington, D.C., www.osha.gov/SLTC/eyefaceprotection
3. Prevent Blindness, Eye Safety at Work, Chicago, Ill., www.preventblindness.org/eye-safety-work

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Eye Protection, Part 2

How to Avoid Fogging

A look at the hidden dangers of lens fogging and how to prevent them

Phil Johnson
Honeywell Safety and Productivity Solutions

IN BRIEF

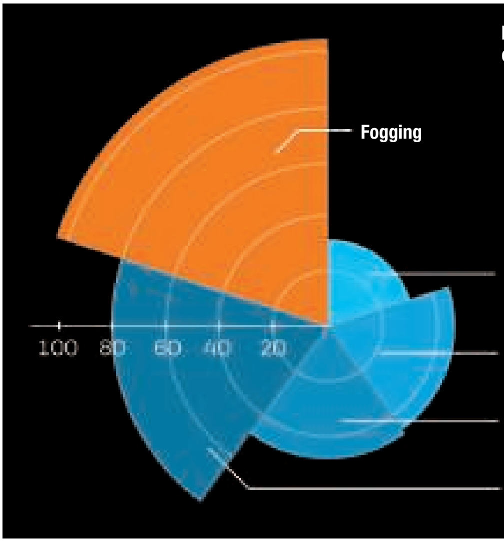

FIGURE 1. Fogging is the main problem faced by safety eyewear users in the chemical process industries

Fogging is the number one problem faced by safety eyewear users in the chemical process industries (CPI; Figure 1). Across applications, both indoors and out, the environments where CPI workers conduct daily tasks are demanding. Fogging on untreated lenses is nearly impossible to avoid.

Lens fogging might seem like no big deal. But maintaining a clear, fog-free view is vital to the wellbeing of CPI workers and employers alike. When tasks are conducted with fog-obscured vision, workers risk not only eye injury but also bodily harm. It takes seconds — or less — for a potentially catastrophic event to occur: a slip or fall; getting struck by equipment or caught in machinery; or coming into contact with harmful chemicals or electrical current. Productivity and compliance are at serious risk, too.

With so much at stake, it's easy to see why employers seek effective anti-fog solutions, and why eyewear manufacturers strive to develop longer-lasting anti-fog coatings. But not all anti-fog-coated lenses deliver the same level of protection or consistency, and until now lenses with anti-fog coating didn't necessarily stand up to the demands of the workplace.

Recent innovations in anti-fog lens coatings have dramatically improved performance. This article examines the dangers and costs of fogging and the differences among anti-fog lens coatings, to help guide safety managers in selecting those that deliver the consistent, long-lasting results required to keep workers safe and productive, and to support employers' bottom lines.

Factors that cause fogging

Lenses fog due to several factors, all of which are related to temperature and humidity.

Environmental heat and humidity. The most obvious reason for fogging is a hot or humid (or both) environment. Whether workers are outdoors in sticky summer conditions or inside a steamy boiler room or food manufacturing plant, moisture in the air causes tiny droplets of water to collect on lenses, primarily the outside surface.

Worker exertion. Lenses fog when workers exert themselves. As an individual's body temperature rises, the heat and sweat produced around the eyes, face and head need to dissipate into the atmosphere. Since safety spectacles, goggles and sealed eyewear all restrict ventilation, moisture condenses and forms fog on the inside surface of the lens.

Transitions between warm and cool environments. Whether workers move from warm to cool environments, such as a hot loading dock to a refrigerated storage unit, or from cool to warm settings, such as a wintry outdoor site to a heated vehicle, transitions between warm and cool environments cause fogging, primarily on the outside of the lens.

Lens washing. A lesser known factor behind fogging is washing. Each time lenses are cleaned with soap and water they are exposed to moisture — the very element they are designed to manage. With each washing, most lenses' anti-fog properties erode, making them less capable of managing water from the environment.

Given the variety and prevalence of factors that contribute to fogging, it is easy to see how fog impacts the majority of workers across most environments.

Impact on safety

Whatever the cause, workers with vision that is obscured by fog cannot clearly see the hazards around them, and are therefore left vulnerable to an array of injuries, from minor bumps to life-threatening harm. Workers who remove their eyewear in the presence of hazards to avoid the hassle and distraction of fog are vulnerable to eye injury from falling objects, airborne particulate matter and splashing chemicals.

Removal of safety eyewear has other safety implications, as well. In addition to the obvious physical hazards, safety eyewear also protects the eyes from harmful visible and invisible light. The effects of overexposure to optical radiation range from eye fatigue, dryness and irritation, to short-term and permanent vision loss. In fact, long-term exposure to the sun's invisible ultraviolet (UV) rays is a leading cause of cataracts and blindness in the U.S. [*1*]. Therefore, when workers remove their safety eyewear — and keep it off — due to fogging, they face greater risk from physical and optical radiation hazards alike.

Impact on productivity

Foggy lenses negatively impact productivity, too. When safety eyewear fogs, workers have little choice but to remove it and wipe it clear, which can lead to repeated interruptions throughout the shift. When eyewear is removed in the work zone, even briefly, work is interrupted and individuals are unprotected. When workers leave the site to dry their lenses away from hazards, productivity takes an even greater hit. The cumulative cost of fog-related interruptions adds up to big reductions in productivity at worksites nationwide.

The cost of noncompliance

Foggy lenses directly impact compliance. It is not uncommon for workers to take off fogging eyewear — and leave it off — rather than deal with the ongoing hassle and distraction of fog. But when workers leave eyewear off altogether, not only are they risking eye injury, they are also in noncompliance with safety regulations, for which employers can incur hefty penalties. Since safety eyewear is a highly visible form of personal protection equipment (PPE), violations are easy for inspectors to spot.

While regulatory fines for noncompliance may seem sizable, consider the cost of noncompliance resulting in an eye injury, such as the following:

- The cost of lost vision to an individual is immeasurable, including medical expenses, diminished quality of life, and the reduced ability to earn a living
- Workplace eye injuries cost U.S. employers an estimated $467 million yearly in direct costs [*2*]
- With indirect costs included, such as legal fees, judgments and training new workers, the estimated total exceeds $934 million annually [*1*]

Despite national and corporate safety programs, approximately 2,000 occupational eye injuries occur in the U.S. every day — more than 700,000 annually — taking a massive toll on workforce health and overall productivity [*3*]. Yet, most safety professionals agree: nearly all occupational eye injuries could be prevented through the proper use of the appropriate eyewear [*1*].

Anti-fog solutions differ widely

While anti-fog solutions include wipes and sprays, the best defense against fogging is a high-performance anti-fog lens coating (Figure 2). Different manufacturers' coating technologies work in different ways, though, with varying levels of success and longevity. Furthermore, the methods used for applying coatings vary widely, resulting in a spectrum of consistency and performance.

When the reservoir of anti-fog agents in the lens is shallow, for instance, those agents are easily wiped or washed away completely after the first few uses. Such eyewear will be worn once or twice, and then be thrown away and replaced. Likewise, a coating whose application isn't closely monitored is likely to deliver inconsistent anti-fog performance and even distort lens optics. Many anti-fog products look good out of the box, but when coating formulations or application methods lack effectiveness or durability, safety eyewear becomes just another piece of disposable PPE that requires frequent replacement.

FIGURE 2. Lens coatings that provide both hydrophilic and hydrophobic properties (right side) are much more effective against fogging compared to traditional anti-fog coatings (left side)

Today's advanced lens coating technologies actively manipulate moisture through surface-acting agents, chemicals designed to move to the lens surface as needed to prevent fogging.

It's important to note there is no national standard for measuring, or requirement for delivering effective anti-fog performance on safety eyewear in North America. Europe's stringent EN166 and EN 168 safety eyewear standards, however, do incorporate the only global test method and certification for resistance to fogging of oculars. The European test requires the submersion of lenses into water for up to two hours, followed by direct, ongoing exposure to fog from test apparatus. Performance is measured in the number of seconds before the lenses fog and disrupt vision. You will find lenses meeting or exceeding these European standards to be superior to those that do not.

Anti-fog technology

Today's advanced lens coating technologies actively manipulate moisture through surface-acting agents, chemicals designed to move to the lens surface as needed to prevent fogging. The most reliable coatings employ dual-action properties: hydrophilic properties that absorb moisture into the lens, and hydrophobic properties that spread excess condensation in a clear film over the lens surface and ultimately shed moisture off the lens.

Applying dual-action anti-fog coating so it goes on and stays on permanently — even after repeated washings and wiping — is key to the coating's durability. Look for manufacturers that bond anti-fog agents permanently to the lens, and those that rely on controlled application methods and vigorous product monitoring that ensure anti-fog coatings absorb, then spread and shed, the greatest amount of moisture consistently over the longest possible time. A long-lasting, consistently fog-free safety lens is one your workers can wear shift after shift with the clear, fog-free view vital to performing their tasks.

Selecting anti-fog eyewear

The following are six tips for selecting effective anti-fog eyewear:

1. Look for anti-fog coatings that employ dynamic, dual-action properties: hydrophilic and hydrophobic.
2. Be sure the manufacturer's batch creation and application processes are rigorously monitored and tested to ensure the highest standard of anti-fog consistency and longevity.
3. Be sure the lens coating application process delivers smooth, consistent results on every pair of eyewear to support exceptional, distortion-free optics.
4. Look for manufacturers using an intense curing process to permanently adhere the coating to the lens. Only permanent coatings will deliver consistent fog-free performance, even after frequent wear, wiping and washings.
5. Look for anti-fog coatings on a wide range of safety eyewear types, from goggles and sealed eyewear to spectacles, as well as lens tints, to provide anti-fog protection to workers across a wide variety of applications.
6. Only eyewear that meets or exceeds Europe's stringent EN166 and EN 168 safety standards have been tested and proven in their effective resistance to fogging of oculars. ■

Edited by Gerald Ondrey

References

1. Prevent Blindness, Eye Safety at Work, Chicago, Ill., www.preventblindness.org/eye-safety-work
2. U.S. Bureau of Labor Statistics, Nonfatal Occupational Injuries and Illness Requiring Days Away from Work, 2013, www.bls.gov/news.release/pdf/osh2.pdf
3 National Institute for Occupational Safety and Health, Washington, D.C.,

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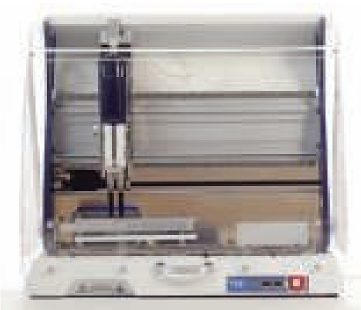

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Interphex 2017, which is taking place March 21–23 at the Jacob Javits Center in New York City, will feature over 625 exhibitors, along with numerous conference sessions, technology demonstrations and networking events, all targeted at global professionals from the from the pharmaceutical and biotechnology industries. The following is a selection of the many products and services that will be highlighted in the exhibit hall at this year's Interphex event.

A new capsule filler with smart formulation software

This company's RoboLQ technology combines precise filling mechanisms and smart formulation software into an all-in-one system for formulating and filling liquid-based capsule products. From separation to filling, the liquid capsule filler streamlines workflow by storing ratio-specific formulas and tracking machine history, all with an output speed of over 2,500 capsules per hour. The RoboLQ is available in four models — Lab, Blend, Thermal and Custom. All models provide precise dosage, ranging from 1 to 1,000 µL. The built-in algorithmic validation mechanism, exclusive to the RoboLQ series, helps to eliminate overfilling by performing a validation check prior to executing a run. This feature reduces spillage and keeps the system clean. Booth 1221 — *CapsCanada, Tecumseh, Ont.*
www.capscanda.com

Hydrogenation reactors with an efficient cooling system

This company's agitated hydrogenation reactors overcome mass-transfer limitations by combining gassing technology with an efficient reactor-cooling system. These design features permit shorter batch times, improved conversion rates and more desirable space-time yields. The company also offers engineering and scaleup services for hydrogenation processes, including not only the reactor itself, but for the complete hydrogenation plant, ranging from laboratory-scale to full-scale industrial plants. In addition to hydrogenation, reactor improvement services are also available for crystallization, polymerization and fermentation processes. Booth 2464 — *Ekato Group, Schopfheim, Germany*
www.ekato.com

These pressure regulators feature a dome-loaded design

The FD Series of compact backpressure regulators (photo) feature an innovative technology based on a dome-loaded, multiple-orifice design that is capable of holding pressure stable across very wide flowrate ranges. Unlike traditional spring-loaded regulators and valves, these devices operate with only one moving part, the wetted diaphragm, which seals directly across the polished array of orifices. For sanitary applications, the FD Series is easily automated with manual or electronic control, and the devices respond in milliseconds to accurately maintain pressure. The crevice-free drainable design features USP Class VI wetted materials. Booth 3473 — *Equilibar, LLC, Fletcher, N.C.*
www.equilibar.com

Inspect over 35 gloves with this wireless testing system

The wireless GTS-WL glove-integrity tester (photo) can simultaneously test more than 35 gloves in just 15 minutes while also documenting results. Radio-frequency identification (RFID) technology allows the glove ports to be clearly identified, and provides glove identification for tracking glove lifeycle. Test protocols are saved in protected storage and can be transmitted via LAN interface to the user's server. The lightweight system's design ensures a correct port fit of the test cover. This enables not only the examination of the glove, but also the tight fit of the glove unit. Booth 3103 — *Metall+Plastic GmbH, a member of Optima Packaging Group, Radolfzell-Stahringen, Germany*
www.metall-plastic.com

A vial-washing machine for low-speed production

The VEGA 2 (photo) is a compact rotary washing machine designed for low-speed production lines. It is able to handle and clean round, brand-

new containers, such as molded and tubular vials, covering the range from 16 to 56 mm. Vials can be directly fed inline onto the in-feed belt of the machine, either from an upstream integrated rotary table, or from trays at 90 deg. The machine can process up to 9,000 vials/h using a continuous-motion positive-transport system. The machine is equipped with up to six customizable washing stations, and the pressure and temperature of the various fluids are monitored to ensure consistent performance. Vials are processed unidirectionally, avoiding any potential contamination. Booth 2545 — *IMA Life North America Inc., Tonawanda, N.Y.*
www.ima-pharma.com

This modular isolator enables fast equipment changeover

The Pharmaceutical Safety Isolator (PSI-L; photo) is a modular, extendable small-scale aseptic processing isolator with a unique L-shaped flange, which enables quick equipment changes to host different filling machines or other pharmaceutical processes. The short decontamination cycle and the return air filter make it a universal, aseptic workspace for the production of aseptic or highly active pharmaceutical products. The isolator and the product machine modules fit together using a "lock and key" principle. The basic unit (L-flange) of the isolator is equipped with an inflatable seal to ensure that the machine module is connected hermetically. Booth 3140 — *SKAN US Inc., Raleigh, N.C.*
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SKAN US

These stability chambers are now 21 CFR Part 11 compliant

This company's stability chambers and stability rooms (photo) incorporate the EZT-570S controller, which is now validated to comply with the FDA 21 CFR Part 11 guidance document for electronic records and digital signatures. The EZT-570S touchscreen controller offers many features designed to simplify chamber operation, including data logging, ethernet control and monitoring from any smartphone or tablet, alarm notification via email or text message, data file backup, full system security, audit trail, digital signatures, power recovery options and more. Stability walk-in rooms may be configured to any size, and temperatures range from –20 to 70°C, with optional humidity range from 20 to 95% relative humidity. Booth 1943 — *Cincinnati Sub-Zero Product, LLC (CSZ), Cincinnati, Ohio*
www.cszindustrial.com

CSZ

A syringe filler with statistical batch control

The Extrafill syringe filler (photo) is a compact machine designed to accommodate two to five filling and stoppering stations to produce up to 12,000 pieces per hour. Batching precision is guaranteed by systems that center the syringes and completely protect them during the filling phase to avoid contamination and to ensure a sterile process. Extrafill is equipped with rotating piston pumps and a statistical batch-control weighing system. The Extrafill's robotic arm peels off the Tyvek protective film and pushes the tub of syringes onto a loading belt to continue toward the filling and stoppering stations. All the production phases are integrated into a single unit designed to combine the two-tub opening and syringe filling/stoppering operations under just one isolator. Booth 3125 — *Marchesini Group S.p.A., Pianoro, Italy*
www.marchesini.com

Marchesini Group

Monitor remote and mobile tanks with this ultrasonic sensor

The Sure Cross U-Gage K50U ultrasonic sensor (photo) is designed for wireless tank-monitoring applications, with either mobile or remotely located tanks and totes. The K50U detects distance from target to sensors ranging from 300 mm to 3 m, and features built-in temperature compensation for accurate measurements. The sensor has a standard 1/4-in. NPT connection, and can optionally be combined with this company's BWA-BK-006 brackets and Q45U wireless nodes. Beyond tank and tote monitoring, the device is also suitable for pallet-presence sensing or monitoring dry material in a hopper. Booth 2471 — *Banner Engineering, Minneapolis, Minn.*
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Instrumentation & Control

special advertising section

IMAGE: ROBERT COUSE-BAKER / FLICKR

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Exciting times for instrumentation and control

Artificial intelligence, the Internet of Things, big data and cybersecurity are all challenges for the instrumentation and control systems of tomorrow

IMAGE: KYLE GORDON / FLICKR

The longevity of industrial control systems makes wise choices essential

Instrumentation and control (I&C) has always formed an essential part of the chemical process industries (CPI). Today, precise and reliable control is more important than ever as operators strive to cut costs and environmental emissions while increasing throughput, reliability, product quality, and safety.

Fortunately, these new challenges are supported by exciting new technical possibilities. The Industrial Internet of Things (IIoT) – "Industry 4.0", as they say in Germany – promises to connect manufacturing and logistics operations to an extent previously unimaginable. Artificial intelligence (AI), after several decades in which the technology mostly fell short of the dream, finally seems able to match the best human brains. Instruments and actuators are more capable than ever before, while wireless networks have slashed the cost of getting data to and from remote locations.

More instruments and more-powerful control systems mean more data to manage – an issue shared with modern plant design and asset-management systems, and indeed with industry as a whole. Combined with AI, the techniques of big data may reveal previously unsuspected relationships between variables. Cybersecurity, meanwhile, will need more attention as devices become more connected.

Our 2017 I&C special advertising section brings news from a range of companies in this sector. We are sure you will find something useful in the following pages. ■

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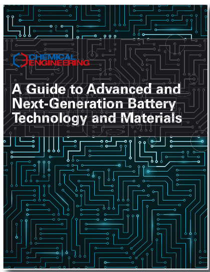


Embedded resource provides customer satisfaction

Professional project services reduce risk and improve project timelines by providing immediate onsite support, explains Endress+Hauser

Large global engineering, procurement and construction (EPC) firms working on substantial petrochemical projects are often challenged by clients to minimize risk, maintain the project timeline and stay on budget, points out instrumentation and control specialist **Endress+Hauser**. Most large EPC companies acquire complex projects that are colossal in scope – not just in terms of their size, but also due to the many stakeholders who are invested in the project. These projects are becoming increasingly complex and demanding. Schedules and budgets are tight, and safety is crucial.

For contractors facing such pressure, embedded resources who join the engineering team can provide expert knowhow and help meet the project's goals, Endress+Hauser notes.

An embedded resource is a subject matter expert who is embedded into the engineering team and works to help reduce risk by providing immediate onsite support. In the case of Endress+Hauser, the products, solutions and services engineer provides

Close collaboration with the firm's engineering disciplines helps to optimize all interfaces to process, control, electrical and piping

knowledge and expertise on process automation field devices. By resolving issues immediately, the embedded resource helps to keep the project on time and on budget. Having this resource also reduces repetitious external communications and the inherent delay caused by emails and phone calls, keeping other resources productive. The manpower is supplied to the project as needed, and also reduces risk of increased direct costs to the project. Close collaboration with the firm's engineering disciplines helps to optimize all interfaces to process, control, electrical and piping.

"Having an Endress+Hauser representative in house is an added value and creates a seamless experience," said Shannon M., Senior Control System Engineer for a large EPC firm. "If a client has an issue or I have a question on dimensions, they are right there to assist."

"We have an embedded Endress+Hauser engineer that works along with our project team. This has helped save time by getting quotes, dimensional data and questions answered in a shorter amount of time. With the right person, this could be beneficial in other projects," said Warren W., the firm's Project Engineer.

Having an embedded resource on the project helps EPC firms provide fast, dependable and reliable services and solutions to their clients.

us.endress.com/embeddedresources

High-frequency radar targets small vessels

With its 80 GHz frequency and small-diameter antenna, VEGA's VEGAPULS 64 works in small vessels where radar level measurement was previously impractical

The current trend in the chemical industry is towards smaller, specialized batches. This results in equipment and containers with reduced volume. But engineers everywhere, including those in technical centres and pilot installations, have frequently run up against limits when they tried to use radar level measurement technology in very small production setups. In particular, factors like the dead band of the sensors, the size and design of the antennas, and measurement uncertainty near the tank bottom often forced them to use weighing systems or pressure transmitters instead.

VEGA's VEGAPULS 64, the world's first radar level sensor for liquids operating at a frequency of 80 GHz, now has an antenna system integrated directly into the process fitting. Since no antenna protrudes into the vessel, it is possible to measure right up to the process fitting itself. This gives greater flexibility because practically all of the container volume can be utilized.

Thanks to the tightly focused measuring beam – with an antenna diameter of 80 mm, the transmission signal has an initial angle of just 3° – using the instrument in tanks with heating coils and agitators has become much easier. Another advantage of VEGAPULS 64 is its larger dynamic range, which results in higher measurement certainty, especially when there is buildup, condensate, foam or a turbulent liquid surface in the vessel.

In pilot plants or applications where very high chemical resistance is required, glass facilities are often used. Because of its small sensor dimensions and small process fittings, the VEGAPULS 64 can be very easily adapted to these applications. Radar sensors are able to measure the level of the product through the surface of a glass container. The tight focus of the VEGAPULS 64 beam makes this much easier than in the past, when big antenna systems have been necessary.

In recent years, non-contact radar level measurement technology has taken over many applications in the chemical industry. The big advantage of radar technology is

Compact size and narrow beam angle make the VEGAPULS 64 ideal for small tanks

its immunity to process conditions such as temperature, pressure and density. With the VEGAPULS 64, levels can now be measured in applications where the process and structural conditions were previously not suitable for radar.

www.vega.com/radar

Automatic repeatable sampling solution

The Sentry ISOLOK automatic sampling system provides a repeatable sample at user–programmable times and intervals, without requiring regular human interaction

The ISOLOK automatic sampling system from **Sentry Equipment Corp.** is available for sampling liquids, slurries and bulk solids, and is especially suited to specialty batch chemical processes. The sampler can be controlled remotely by a Sentry controller or a distributed control system (DCS). Controllers and remote operating modules are available in a variety of configurations. Users can change the programming, sample time and other parameters if the sampler is used for multiple products within the same reactor, for example.

The ISOLOK system minimizes waste, as the volume of the sample can be controlled precisely. It can be customized to provide a sample directly to an analyzer, and to allow real-time dosing of dilution agents to minimize safety risks from the need to handle hazardous samples.

The ability to get a sample whenever desired, in the volume desired, in the same manner every time is a huge aid to achieving consistent process performance. Automated sampling removes any doubt about how or when a sample was taken. The ISOLOK captures fixed sample volumes at fixed time intervals, for uniformity and consistency. This virtually eliminates operator error. Sampling events can be triggered by control parameters such as reactor temperature or concentration. This eliminates overdosing of chemicals and may allow reaction times to be optimized.

This ISOLOK SAL-B sampler integrates an ISOVALVE ball valve into the body to ease inspection and maintenance

Designed for harsh environments, ISOLOK samplers feature rugged stainless steel construction. Specialized alloys and sealing materials are available. Options include port closures, various container types, sampler enclosures (with or without heaters), sample heating, and refrigeration.

ISOLOK samplers are designed with practicality in mind. For example, the ISOVALVE ball valve built into the sampler body on the model SAL-B provides added safety and convenience during inspection or maintenance. When off-line inspection or maintenance is needed, the ISOVALVE can be closed and the entire sampler removed while the process line remains in pressurized service. For safety, telltale ports on the isolation valve allow verification that pressure has been relieved before the sampler is detached. **www.sentry-equip.com**

Keys to correctly specifying control valve technology

Brian Kettner of Badger Meter explains how careful thought during the process of sizing control valves can maximize performance while controlling costs

Control valves play a vital role in modern chemical plants. They are the most important single element in any fluid handling system, because they regulate the flow of fluid to the process.

The style of control valve is usually determined by the user's requirements, past experiences, or plant preference. Valve selection can be a tricky process, but sizing the valve can be even more difficult.

When choosing a valve, the most important variables to consider are:

- What medium will the valve control?
- What effects will specific gravity and viscosity have on the valve size?
- What will the inlet pressure and temperature be at maximum demand?
- What pressure drop will exist across the valve at maximum demand?
- What maximum capacity should the valve handle?
- What is the maximum pressure differential for closing the valve?

Frequently, control valves are sized based on a future maximum process design plus a safety factor. This leads to specifying, buying, and maintaining a larger device than is needed for the flowrate, and results in imprecise control and poor production outcomes. The general rule is to size a valve so that it operates somewhere between 20–80% open at maximum required flowrate and whenever possible, and not much less than 20% open at the minimum required flowrate.

Careful selection maximizes control valve performance

Chemical companies frequently choose globe-style valves due to their proven performance and lifecycle advantages. Some globe valve designs feature a bolted bonnet and post-guided inner-valve. They are well suited for modulating control of liquids and vapors in environments where compact size and the ability to withstand high temperature and pressure are essential. Valves are also available with a pre-formed diaphragm and multi-springs to ensure extremely linear travel versus input signal performance. Models utilizing a single "O" ring and Nylatron guide bushing provide minimum hysteresis. Another significant improvement in control valve technology is the use of 316 stainless steel for trim material such as the valve body, bonnet and inner valve. This ensures longer trim life, and as such, less downtime and lower device repair and replacement costs.

Key to any control valve project is the assistance of qualified engineers, who analyze the application to ensure the right instruments are selected and sized correctly. Valve manufacturers who understand control performance can share those capabilities and show they can conform to a user's performance specifications.

www.badgermeter.com

Guided wave radar simplifies oil well cementing

Fast response time and full-probe-length measurement from Magnetrol guided wave radar technology help drive performance for oil well cementing trucks

Pumping cement into a borehole is one of the most critical steps in oil and gas well production. The injected slurry hardens to form a protective sheath that isolates the well from surrounding geologic features. Cementing is typically among the first operations to prepare a well for production, and one of the last before it is abandoned.

Cement is often mixed and injected using mobile cementing trucks. These feature bulk transport or batch mixing units, control systems, and high-pressure pumps to force the slurry down the casing.

The mixing system blends Portland cement, water, and additives to control the density, setting time, and other properties of the slurry. Control systems typically include automatic density control and data recording systems. Level control within the slurry storage tank is a key part of this.

Level measurements must be precise and responsive, since delays can damage cementing systems and shut down operations when tanks exceed their high or low level limits. In addition to being accurate, responsive, user-friendly and reliable, the mobile level controls must also be extremely robust to tolerate the day-in, day-out concussions of oilfield travel.

Magnetrol's ECLIPSE system (upper right) is key to accurate mixing and pumping

A leading manufacturer of cementing equipment in China needed level controls that could match this specification. The company selected **Magnetrol International's** ECLIPSE guided wave radar (GWR) level transmitter with an overfill-capable probe installed in an external cage with a 31 in. (800 mm) center-to-center measurement range. The closed coaxial design tends to reject false targets caused by foam, while the probe's high accuracy ensures safe and efficient operation. A convenient user interface makes configuration and field adjustments quick and easy.

Magnetrol won the business after the ECLIPSE guided wave radar unit was tested against competitive GWR instruments. Two advantages gave ECLIPSE transmitters the edge. First, their response time of less than one second showed operators the level in real time. Competitors' units required a full 10 seconds to respond.

Second, the overfill-safe probe delivered outstanding performance, giving accurate level readings to the top of the probe and close to the very top of the tank. By demonstrating best-in-class transmitter response time and full probe measurement range, Magnetrol won the order for more than 100 ECLIPSE GWR transmitters.

www.magnetrol.com

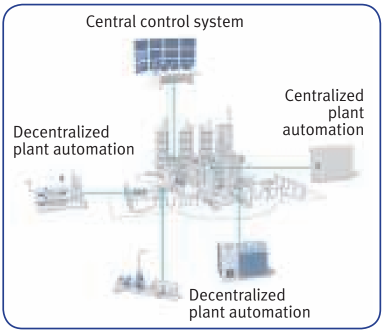
Towards modular automation in the process industries

Phoenix Contact is active in the evolution of "Industry 4.0", which uses modularization and connectivity to make plants more agile and quicker to configure

To be successful in international competition, companies need a great deal of flexibility in responding to changing conditions and adapting quickly to new requirements, points out communications and interface specialist **Phoenix Contact**. Versatile plants are the way forward: modular production provides the flexibility needed to introduce new products to market faster and at competitive prices.

This challenge in the process industry can be mastered with the help of intelligent technology. NAMUR, the User Association of Automation Technology in the Process Industries, and ZVEI, the German Electrical and Electronic Manufacturers' Association, are active in specifying the requirements for automation technology and developing the necessary solutions. NAMUR recommendation NE 148, for instance, specifies what is expected of a modern automation system and thus defines what Industry 4.0 means for the process industry. ZVEI, meanwhile, is aiming to develop a common standard for enabling modular automation in the process industry on the basis of current control systems.

Modular automation will create substantial advantages, especially for pharmaceuticals and fine chemicals. For example, the time needed for engineering, implementation and maintenance is cut by up to 50% (source: ZVEI white paper) because modular automation summarizes procedural functions and thus greatly reduces complexity. Production is set up and tested as a chain of modules, each of which is supplied fully functional and includes a digital description. Once the pipework is connected, the higher-level process control only needs to handle the parameterization that orchestrates the interaction of the modules. Increasing demand is handled by setting up additional production units in parallel. Even world-scale plants with central control systems will benefit from the simple integration of prefabricated modules, such as compressors.



Even in large plants, modularization of process control will bring advantages

Phoenix Contact is very active on the subject of Industry 4.0 in the process industry, working on the committees that are drawing up the necessary technical standards. Synergies between machine and plant automation and the modular process industry are used to advantage. In time, modular automation in the process industry will get new products to market much quicker.

www.phoenixcontact.com

High-precision electric actuators

AUMA offers high-precision compact actuators for heating, cooling, and metering applications

AUMA SDL linear actuators provide high positioning accuracy for modulating applications

AUMA's compact electric actuator ranges offer precise, robust and reliable flow control solutions even under difficult process conditions. Their compact design makes them ideally suitable for space constraints and small valves. Typical applications include demanding temperature control systems in the food and chemical industries, and fluid metering duties.

AUMA offers two families of compact actuators: Basic Range and Smart Range. Basic Range SBA linear actuators and ED/EQ part-turn actuators offer all the essential functions, including feedback signals, in robust packages. SBA linear actuators provide high positioning accuracy and are suited to modulating applications.

AUMA's Smart Range includes SDL/SDG linear actuators, SVC globe valve actuators and SGC part-turn actuators. All have variable-speed motors that provide soft starts and stops for gentle treatment of mechanical components, and allow variable-speed operating profiles to minimize pressure surges and cavitation. Operating parameters can be set via software, and Modbus RTU and Profibus DP interfaces are available.

The SDL/SDG actuators feature low energy consumption, making them particularly suited to remote sites and solar PV power systems. They are also insensitive to voltage fluctuations.

AUMA's compact linear actuators cover thrusts of 0.6–25 kN and strokes of 35–300 mm. Part-turn actuators are available for torques of 25–1,000 Nm. Globe valve actuators offer torques of 10–100 Nm, with strokes from 60–70 mm. **www.auma.com**

AI helps automate thermal power plants

Full automation of thermal power plants with the help of artificial intelligence (AI) took a step forward earlier this year when Mitsubishi Hitachi Power Systems, Ltd. (MHPS; Yokohama, Japan; www.mhps.com) announced that it had successfully tested an AI-based solution for combustion tuning in boilers. The trial at Taiwan Power Co.'s Linkou Thermal Power Plant (New Taipei, Taiwan) showed results comparable to those a highly experienced engineer could achieve, MHPS said.

By analyzing large volumes of complex digital data acquired during boiler operation, AI-based boiler control systems can help to minimize operating costs and detect problems in good time, MHPS said.

Combustion processes in thermal power plants are optimized by adjusting parameters including flue-gas emission characteristics, combustion balance, steam temperature, and boiler efficiency. During the tests in Taiwan, the AI system proposed parameters that were essentially no different from those set by an experienced engineer, MHPS said.

Linkou Power Plant, Taiwan, where MHPS has been testing the new combustion control technology

MHPS will continue to enhance the AI-based combustion tuning system at the Linkou power plant. Combustion tuning is a core element of a comprehensive system, currently under development, that will eventually enable AI-controlled operation of thermal power plants.

MHPS previously delivered three sets of boilers and steam turbines, each rated at 800 MW, to the supercritical coal-fired plant at Linkou. The first set has already started commercial operation, and the second is scheduled to go into service in the next month or so. ■

This turbopump is small but mighty

The HiPace 30 from Pfeiffer Vacuum performs strongly

The HiPace 30 turbopump is the only turbopump on the market in its size class offering pumping speeds of 32 l/s, says manufacturer **Pfeiffer Vacuum**. Its small installation footprint and low level of vibration make this pump particularly suitable for integration into compact analytical systems such as benchtop mass spectrometers, small electron microscopes, and leak detectors. Furthermore, weighing as little as 2 kg overall makes the HiPace 30 ideal for mobile applications.

The sophisticated rotor design of the HiPace 30 achieves high gas throughputs and very good compression of light gases.

At just 2 kg, the HiPace 30 by Pfeiffer Vacuum is ideal for small and mobile systems

This ensures the low residual gas background that is desirable for mass spectrometry applications.

The HiPace 30 is designed with a so-called hybrid bearing. This combination of ceramic ball bearings on the backing vacuum side and permanently magnetic radial bearings on the high vacuum side makes for a particularly sturdy bearing design. The pumps therefore have a long life, with a maintenance interval of approximately four years. **www.pfeiffer-vacuum.com**

Particle Impact Problems in Pneumatic Conveying

Pneumatically conveyed solid materials inevitably impact pipe walls and other particles, which can create processing and equipment problems. Provided here is an outline of potential problems related to particle impacts and the physics behind them

David Mills
Consultant

Among the defining features of pneumatic conveying is the flexibility that can be achieved with pipeline routing for the transport of bulk particulate materials in a totally enclosed environment. Powdered and granular materials can be conveyed vertically up and vertically down, as well as horizontally, in a single continuous routing, just by using bends in the pipeline. By this means, any obstructions in the routing can be avoided simply by routing the pipeline around them.

In traversing a pipeline, however, there will inevitably be impacts between the particles being conveyed and the retaining pipeline. This will be particularly so at each bend in the pipeline, where the particles will be subject to a change in direction, regardless of pipeline orientation. The impacts also lead to reductions in particle velocity. In horizontal sections of pipeline, there will be a natural tendency for the particles to fall to the bottom of the pipeline due to gravity. In this case, the particle impact is likely to be a glancing blow and hence at a low angle of impact. The situation with regard to bends, however, is very different because all the material will have to take the turn, and, as a consequence, there will be a considerable number of particles impacting with the bend wall, as well as particle-to-particle interactions in the turbulence generated. The geometry of the bend is an additional variable here because the radius of the bend will have a major influence on the impact angle. This article provides information about the behavior of pneumatically driven solid materials and the problems that can arise due to impact of the solids on pipe walls and other particles. These include pipe wear, particle degradation, dust formation and others.

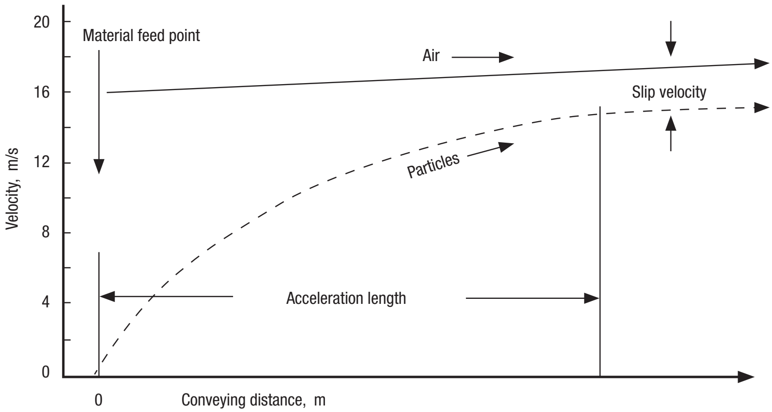


FIGURE 1. Pneumatically conveyed particles accelerate from the feeding point in the pipeline

Conveying air velocity

Conveying air velocity is a critical parameter in pneumatic conveying. From basic fluid mechanics, pressure drop is directly proportional to the square of the velocity. Therefore, the air velocity must be kept to as low a value as possible to avoid excessive pressure drop. In pneumatic conveying, however, the objective is to have the conveying air velocity maintained at a minimum value that is still sufficient to reliably convey the material. For materials conveyed in dilute phase (suspension flow) this velocity is likely to be in the range of 15 m/s (~3,000 ft/min), and for many materials, dilute-phase conveying is the only option with a conventional pneumatic conveying system. For materials with good air-retention characteristics or good permeability, however, dense-phase conveying may be possible. In this case, the minimum conveying air velocity may be as low as 5 m/s (~1,000 ft/min). A safety margin of about 20% on conveying air velocity is generally recommended. The margin, however, must not be too great because pressure drop, and hence energy required, varies approximately with the square of the velocity.

In pneumatic conveying, engineers generally refer only the velocity of the air (rather than the velocity of particles being conveyed), since this quantity can readily be calculated or measured. The particles in the air stream will be conveyed at a slightly lower velocity. The difference in velocity between the air and the particles in it is generally referred to as the "slip velocity." The value of the slip velocity will increase with larger particle sizes, higher particle densities and more complex particle shapes (higher surface area).

The routing of the pipeline may include sections where particles are moved vertically up and vertically down in order to cross roads or railways, or to avoid obstructions. Flow vertically up and down presents no undue problems, and is potentially easier, since the minimum conveying air velocity for flow vertically up is generally lower than that for horizontal flow. In reality, there are few cases where this advantage can be exploited, since most pipelines incorporate combinations of both horizontal and vertical pipeline. Most of the time, horizontal pipeline predominates, so conveying air velocities are generally specified in terms of those required for horizontal conveying.

BASIC EQUATIONS

$$\Delta p_{acc} = (1 + \phi)\frac{\rho_2 C_2^2}{200} \text{ mbar} \quad (\mathbf{1})$$

where $\phi = \dfrac{\dot{m}_p}{3{\cdot}6\ \dot{m}_a}$ = solids loading ratio

Where $\dot{m}_p$ = product mass flowrate, ton/h
Where $\dot{m}_a$ = air mass flowrate, kg/s
The 3·6 term is required to render the value dimensionless
ρ_2 = air density at end of pipeline, kg/m^3
and C_2 = conveying line exit-air velocity, m/s

Energy loss

When a material is fed into a pipeline, the particle velocity at the feeding point is essentially zero. It is important, therefore, that the material should be able to be accelerated to its terminal velocity in a straight section of pipeline, either horizontally or vertically. The length of pipeline required for this is termed the "acceleration length," and will depend upon the particle size, shape and density of the material to be conveyed. For dust and fine powders, this is likely to be on the order of 1–2 m (3–6 ft), but for small granular particles and pelletized materials, the length may be on the order of 5–6 m (16–20 ft). Within the acceleration region, however, the pipeline should be as straight as possible to allow the particles to reach their terminal velocity as quickly as possible. If bends are placed too close together, before a steady flow is established, the flow could stall and the pipeline may block.

The situation is illustrated in Figure 1 [*1*], which plots the acceleration of the conveyed particles following their feed into a pipeline, at essentially zero velocity, to the point at which they reach their terminal velocity. A significant element of the conveying-line pressure drop, at the start of the pipeline, can be attributed to this acceleration process. In a single-bore pipeline, the values of both the air and particle velocities will continue to increase along the length of the pipeline as the material is conveyed to the discharge point.

It must be recognized that the pipeline will be prone to blockage over much of this acceleration length. It is essential, therefore, that there should be no bends or other possible obstructions to flow in this region. The actual value of the acceleration length will depend very much on the particle size, shape and density of the conveyed material. For fine powders, it may be as little as a couple of meters (~6 ft) but for coarse granular materials it might be 6 m (~20 ft) or more.

Since the material that is fed into a pipeline is essentially at zero velocity, a significant element of pressure drop for the conveying system is that of accelerating the particles from zero

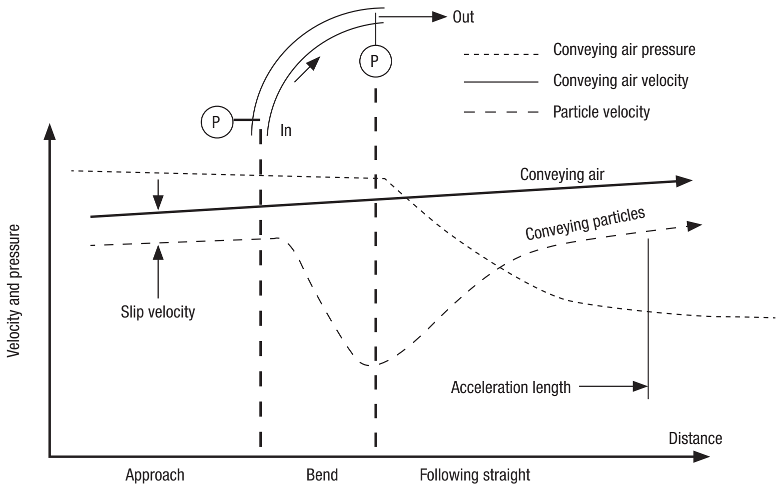


FIGURE 2. The figure shows changes in pressure and velocity as particles flow through a pipe bend

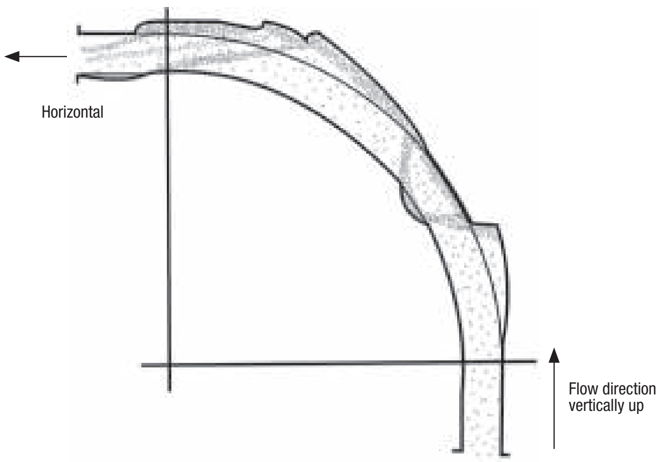


FIGURE 3. Wear patterns in pipe bends can be influenced by deflected particles

velocity to their final terminal velocity at the discharge point from the end of the pipeline. The acceleration pressure drop, Δp_{ACC}, is based on exit values for both air density and conveying air velocity, and can be evaluated from Equation (1); (see box above).

This equation will take into account the acceleration for both the conveying air and the conveyed material. For greater accuracy, should it be needed, account can be taken of the fact that the air will have a significant value of velocity at the pipeline inlet, since it must be high enough to convey the material, and the particles will be at a slightly lower velocity than that of the air at the pipeline outlet by virtue of the necessary slip velocity.

Because air is compressible, the velocity of the conveying air will gradually increase along the length of a single-bore pipeline as the material is conveyed to its destination point. Problems of pipeline wear and particle degradation, as well as power requirements for system operation, will all increase with an increase in velocity. This will be the case for both positive-pressure and vacuum-conveying systems. If high pressure or vacuum is used for conveying, it is essential that the bore of the pipeline be stepped up part of the way along its length to minimize these problems. The location of the step in the pipeline, however, is critical. If it is positioned too early, the conveying air velocity may be below the minimum value for the material being conveyed, and the pipeline will block.

IMPACT PROBLEMS

If the material to be conveyed is potentially abrasive, significant wear of the pipeline, and particularly the bends in the pipeline, is likely to occur. If the material being conveyed is potentially friable, significant damage to the material being conveyed may occur, and it is possible that these changes to the material could affect the conveying performance of the material itself. If dust generated from the material is potentially explosive, there is the possibility that such degradation could result in an explosion. As a result of particle impact, particularly against bends, there is potential for heat generation, which can result in particle melting and in the formation of streamers, often called "angel hairs."

As a consequence of particle impact, particularly against bends, there will be a significant reduction in particle velocity. These particles will then have to be re-accelerated back to their terminal velocity, which will add significantly to the pressure drop — and hence, energy loss — for the conveying system, as seen by Equation (1). It is not only after the feed point into the pipeline that an acceleration length needs to be established. There will be a significant reduction in particle velocity for particles after exiting a bend, and particularly so after short-radius bends. This situation is illustrated in Figure 2 [*1*].

Considering the conveying air pressure, there will be a gradual fall in pressure along the entire length of the pipeline. Within the bend itself,

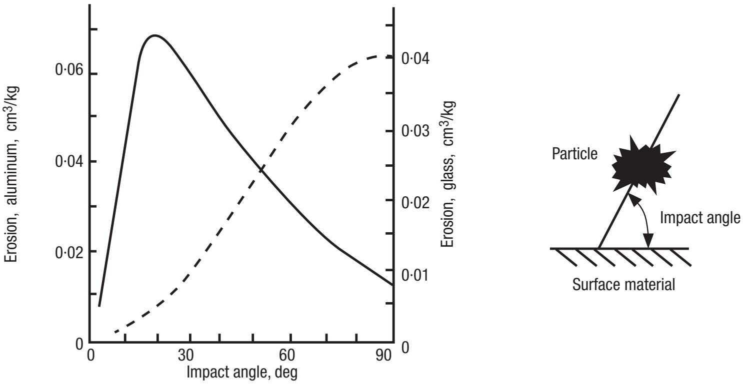


FIGURE 4. Impact angle is an important variable for erosive wear of various surface materials

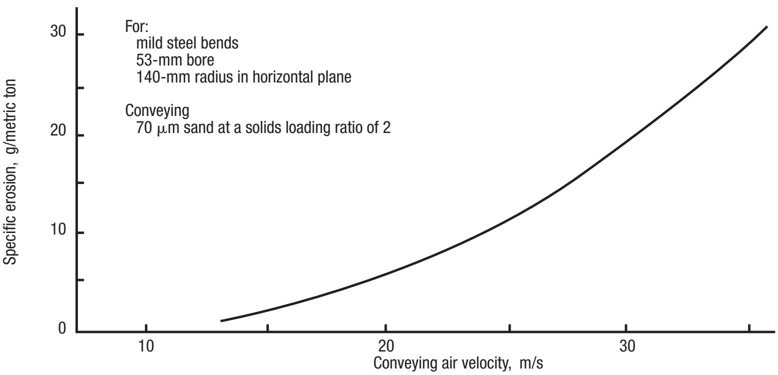


FIGURE 5. Erosive wear is also influence heavily by particle velocity in pipeline bends

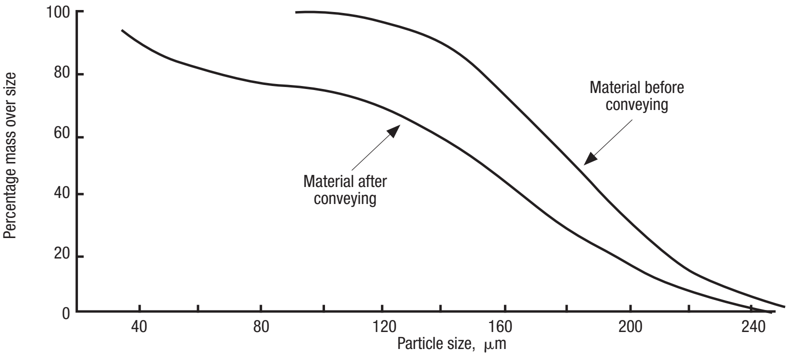


FIGURE 6. Pneumatic conveying can shift the cumulative particle size distribution of a material, especially for friable solids

there will be a small pressure drop, but the major part of the loss in pressure, as a result of the flow though the bend, will be in the acceleration of the particles back to their terminal velocity following the bend. The two pressure gages included in Figure 2, at the bend inlet and outlet, will give a false reading for the actual pressure drop, which results from the flow of material through the bend. In pneumatic conveying situations, most of the pressure drop that can be attributed to the bend occurs after the bend, in terms of the need to re-accelerate the particles back to their terminal velocity.

Erosive wear

The erosive wear of bends in pneumatic-conveying-system pipelines is well illustrated by the work of Mason and Smith [*2*]. They carried out tests on 25- and 50-mm (1- and 2-in.) square-section 90-deg bends with a flow of alumina particles from vertical to horizontal. The bends were made of Perspex (polymethylmethacrylate) and were constructed with substantial backing pieces so that the change in flow pattern and wear over a period of time could be visually observed. The results from one of their tests are given in Figure 3.

With a new bend, the particles tend to travel straight on from the preceding straight pipeline until they impact against the bend wall. After impact, they tend to be swept around the outside surface of the bend. They are then gradually entrained in the air in the following straight length of pipeline. In Figure 3, the flow pattern is shown after substantial wear has occurred. This shows quite clearly the gradual wearing process of a bend and the effect of impact angle on the material in the process. Erosion first occurred at a bend angle of about 20 deg, which became the primary wear point, as one would expect. After a certain depth of wear pocket had been established, however, the particles were deflected sufficiently to promote wear on the inside surface of the bend, and then to promote a secondary wear point at a bend angle of about 75 deg.

A small tertiary wear point was subsequently created at a bend angle of about 85 deg. If such a highly reinforced bend were to be used in industry, in preference to replacing worn bends, the deflection from the latter wear points would probably cause erosion of the straight section of pipeline downstream from the bend. Because this pattern of particle deflection in worn bends is now well recognized, some companies manufacture steel bends with thicker walls. They are also slightly thicker on the inside surface to allow for the fact that particles can be deflected to the inside surface, as illustrated in Figure 3.

Impact angle and surface material. A curve presented by Tilly [*3*], and shown in Figure 4, illustrates the variation of erosive wear with impact angle for two different surface materials, and is typical of the early work carried out to investigate the influence of these variables. Both materials showed very significant differences in both erosion rate and the effect of impact angle. These materials do, in fact, exhibit characteristic types of behavior that are now well recognized. The aluminum alloy is typical of ductile materials: it suffers maximum erosion at an impact angle of about 20 deg, and offers good erosion resistance to normal impact. Glass is typical of brittle materials: it suffers severe erosion under normal impact, but offers good erosion resistance to low-angle, glancing impacts.

These tests were carried out with sand particles sieved to particle sizes of between 60 and 125 µm. The particles were impacted at a velocity of about 100 m/s, since they were undertaken specifically for the investigation of the potential wear of aircraft engines. That brittle and ductile materials respond to erosion in very different ways can be clearly seen from Figure 4, and it is obvious that different mechanisms of material removal must be involved. Note that the two vertical axes relate to the two different materials that were eroded, and that they have very different scales.

Theories proposed. From early thoughts on the matter, it was suggested that for ductile materials (annealed low-carbon steel, copper, aluminum and so on), removal of material occurs predominantly by plastic deformation. No cracks propagate ahead of the cutting particle and the volume removed is due entirely to the cutting action of the particle, rather like the cutting edge of a machine tool. For brittle materials (glass, basalt, ceramics, cast iron, concrete and so on), it was thought that material removal occurs in large part due to the propagation of fracture surfaces into the material.

These erosion processes, however, have subsequently proved to be less straightforward. Photographs taken of impact craters, produced as a result of single-particle impact studies, have shown clear evidence that melting of the pipe material can take place. The melting only occurs over a small part of the impact crater, but it must be considered to contribute to the erosive wear process.

Influence of velocity. The author has undertaken research into the erosion of pipe bends in pneumatic conveying systems at velocities appropriate for dilute-phase suspension flow. Tests were carried out over a range of conveying air velocities from 15 to 35 m/s (3,000 to 7,000 ft/min). Steel bends of 53 mm (2 in.) bore having a ratio of bend diameter, *D*, to pipe bore, *d*, of about 5:1 were eroded by 70-µm sand. Over the ranges tested, the velocity exponent was found to be consistent at 2.65. A graph showing the influence of conveying air velocity on the specific erosion of the bends is given in Figure 5 [*1*].

The solids-loading ratio is the dimensionless ratio of the mass flowrate of the bulk particulate material conveyed, to the mass flowrate of air used to convey the material. For dilute-phase, suspension-flow conveying, solids-loading ratios are typically up to about 15. For low-velocity, dense-phase conveying, solids-loading ratios generally need to be greater than about 40.

The erosion is in terms of the mass of metal eroded from a bend per ton of sand conveyed through the bend. With a velocity exponent of 2.65, this means that the wear rate will increase by a factor of six with a doubling of the air velocity. This explains why the curve rises so steeply in Figure 5. If a positive-pressure conveying system operates at a pressure of 1 barg (15 lb/in.^{2}), a doubling of the velocity will be achieved in a single-bore pipeline discharging to atmospheric pressure. With a vacuum conveying system, a doubling in velocity will be achieved with a system exhausting at 0.5 bar absolute (7.5 lb/in.^{2}). In such a system, a bend at the end of the pipeline will wear approximately six times as fast as a bend at the start of the pipeline.

If an abrasive material is to be conveyed, therefore, it would always be recommended that the pipeline be stepped to a larger bore partially along its length in order to limit the maximum value of velocity achieved, in order to minimize the erosive wear of bends toward the end of the pipeline. It is essential, of course, that the step to the larger-bore pipeline is correctly positioned along the pipeline, for if the velocity falls below the minimum value of conveying air velocity at the step, the pipeline is likely to block at this point.

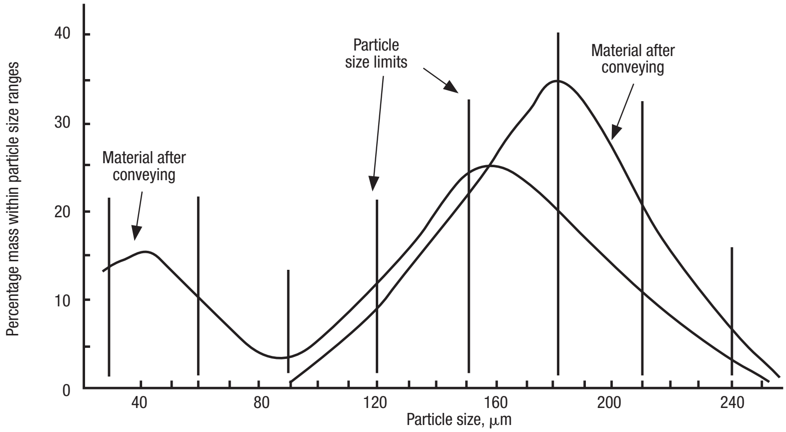


FIGURE 7. Pneumatic conveying can affect the fractional size distribution of a friable material

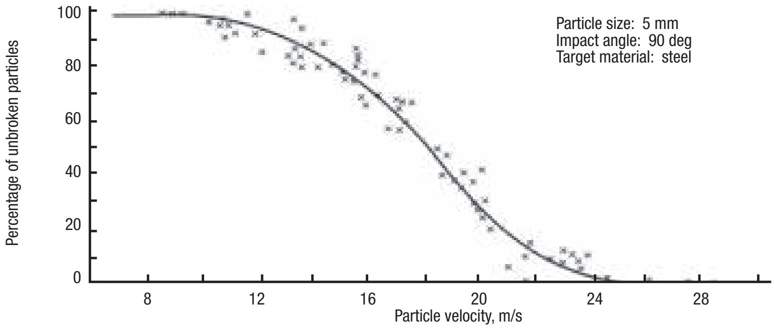


FIGURE 8. These data show how particle velocity can influence the degradation of 5-mm aluminium oxide particles

Particle degradation

In some bulk-solids-handling processes, intentional breakdown of the material is required (crushing, grinding and comminution). In many handling and storage situations, how-

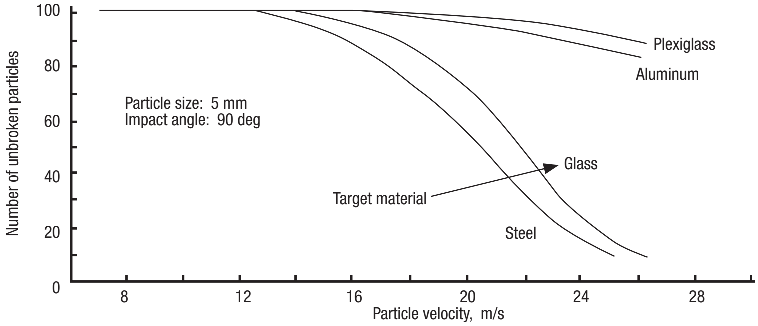


FIGURE 9. Different target materials, including glass, steel and aluminum, affect the degradation of aluminium oxide particles

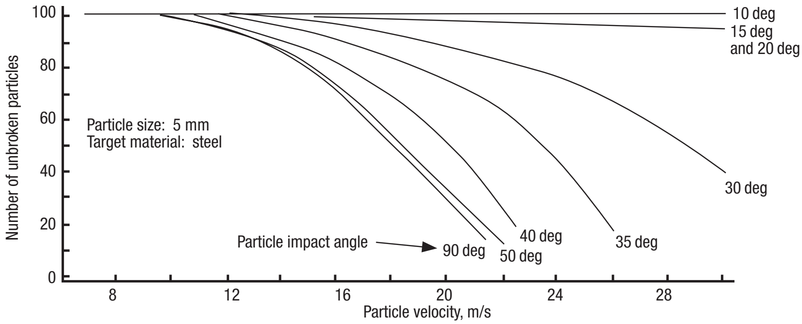


FIGURE 10. These data show how different impact angles affect the degradation of aluminum oxide particles

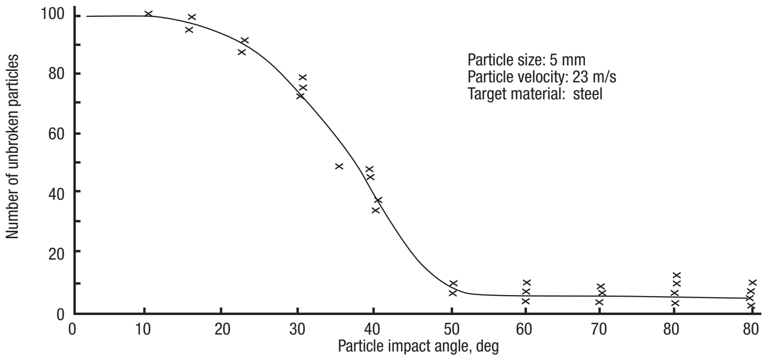


FIGURE 11. This graph takes a slice of particle-impact data from Figure 10 at a particular particle velocity and shows the affect on particle degradation

ever, unintentional breakage occurs. This is usually termed degradation or attrition, depending on the mechanism of particle breakage. Bulk materials, when pneumatically conveyed, will impact against bends in the pipeline, and there may be a significant amount of particle-to-particle interaction. There may also be frequent impacts against the pipeline walls, and particles sliding along the pipeline walls in low-velocity, dense-phase flows. These collisions and interactions will produce forces on the particles that may lead to their breakage.

Particle breakage. If particle breakdown occurs easily, the bulk solid is said to be friable. Tendency for particle breakdown occurs by three main mechanisms. The first is a tendency to shatter or degrade when the bulk solid is subject to impact or compressive loading. The second is the tendency for fines and small pieces to be worn away by attrition when bulk solids either rub against each other or against some surface, such as a pipeline wall or bend. The third is the tendency for materials, such as nylons and polymers, to form "angel hairs" when conveyed, as a result of micro-melting, which occurs to due to the frictional heat of particles sliding against pipeline walls.

Of all conveying systems, dilute-phase conveying probably results in more material degradation and attrition than any other. This is because particle velocity is a major factor in the problem and, in dilute-phase conveying, high velocities have to be maintained. The potential influence of a pneumatic conveying system on a material is demonstrated in Figures 6 and 7. This is a consequence of conveying a friable material at a high velocity in dilute-phase suspension flow in a conveying system with a large number of small-radius bends [*1*].

Figure 6 shows the influence on the cumulative particle-size distribution for the material before and after conveying. The mean particle size, based on the 50% value, has changed from about 177 to 152 µm. The really significant effect, however, is shown in the fractional size-distribution plot in Figure 7. In this alternative (and essentially magnified) plot, the potential effect of degradation on the material can be clearly seen. A considerable number of fines are produced, and even on a percentage mass basis, these cause a significant secondary peak in the particle-size distribution.

Operating problems. Particle degradation can cause problems in a number of areas because of changes in particle shape and particle-size distribution that can result. It is a particular problem with chemical materials that are coated, for it is the coating that is generally the friable element of the resulting material. Plant operating difficulties are often experienced because of the fines produced, and problems in handling operations can also result after the material has been conveyed.

Apart from the obvious problems of quality control with friable materials, changes in particle shape can also lead to subsequent process difficulties with certain materials. The appearance of the material may also change, making it not as readily sold. Changes in particle-size distribution can affect flow characteristics, which in the extreme, can change a free-flowing material into one that can only be handled with great difficulty, and with materials intended for subsequent sale, this can lead to customer problems.

Filtration problems. In pneumatic conveying systems, plant-operating difficulties can result if degradation causes a large percentage of fines to be produced, particularly if the filtration equipment is not capable of handling the fines satisfactorily. Filter cloths and screens will rapidly block if they have to cope with unexpectedly high flowrates of fine powder. The net result is that there is usually an increase in pressure drop across the filter, and this could be a significant proportion of the total pressure available in a low-pressure system.

Flow problems. In many systems there is a need to store the conveyed material in a hopper or silo. Flow functions can be determined for bulk particulate materials, from which hopper wall angles and opening sizes can be evaluated, to ensure that the material flows reliably at the rate required. A change in particle-size distribution of a material, as a result of conveying operations, however, can result in a significant change in flow properties. Thus, a hopper designed for a material in the "as-received" condition may be totally unsuitable for the material after it has been conveyed. As a result, it may be necessary to fit an expensive flow aid to the hopper to solve the problem.

Potential explosion problems. Many solid materials, when they occur in a dust cloud, can ignite and cause an explosion. Dust clouds are clearly quite impossible to avoid within a pneumatic conveying system, and so this poses a hazard with regard to the safe operation of such systems. Of those materials that are potentially explosive, research has shown that it is only the fraction of the material with particle sizes less than about 200 μm that poses the risk of explosion. Degradation and attrition caused by pneumatic conveying, however, can result in the generation of a considerable number of fines, particularly if the material is friable. Even if the material did not present a problem with respect to explosions in the "as-received" condition, the situation could be very different after the material has been conveyed [*4*].

The influence of velocity. The results of a program of tests [*1*] carried out with 5-mm spherical aluminum-oxide particles impacted at 90 deg against a steel target are presented in Figure 8. In this plot, the experimental data have been included to show how the relationship was derived and to show the limits of scatter in the results.

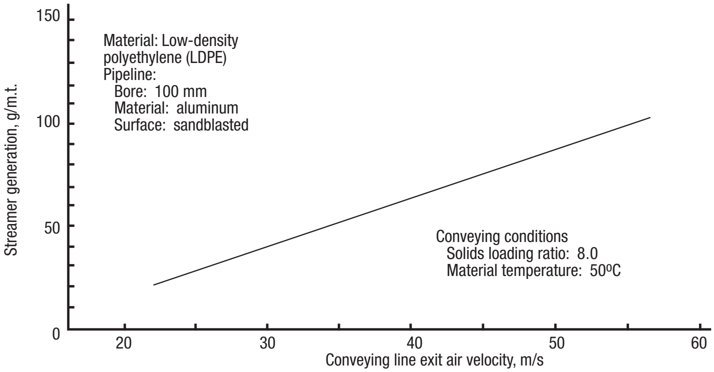


FIGURE 12. Low-density polyethylene (LDPE) pellets can degrade by forming "streamers"

Figure 8 shows that there is a very rapid transition in particle velocity from zero breakage to total degradation. Below a particle velocity of about 9 m/s, only elastic deformation occurs and there is essentially zero particle degradation. Above a particle velocity of about 25 m/s, however, the stress induced by the impact is always sufficient to damage every particle. It is interesting to note that within the transition region, the number of unbroken particles at any given velocity is very consistent, and that a smooth transition is obtained from one extreme to the other over this range of velocity.

The influence of surface material. With erosive wear of surface materials, it has been found that the resilience of the surface material can have a significant influence on erosive wear, and that rubber and polymers can offer better wear resistance than metals having a very high hardness value in certain cases. Since the mechanisms of erosion and degradation have many similarities, it is quite possible that resilient materials could offer very good resistance to particle degradation.

The results of tests carried out on four different target materials with the 5-mm spherical aluminum-oxide particles are presented in Figure 9. In each case, the targets were 5-mm thick and they were impacted by the aluminum oxide particles at 90 deg. This shows very clearly that target material can have a very marked effect on degradation.

Although there is little difference in the maximum value of particle velocity at which no degradation occurs, varying from 12 m/s for steel to about 17 m/s for Plexiglas (poly methyl methacrylate) and aluminum, very significant differences exist in the transition region between no degradation and total degradation. In the case of the steel and glass targets, the transition is very rapid. For the aluminum and Plexiglas, however, the transition is very slow, and so a high-velocity impact against these materials would only result in limited damage occurring.

The influence of particle impact angle. Particle impact angle is the same as that used in the above erosive-wear work (Figure 4). Impact angle has been shown to be a major variable with regard to the erosive wear of surface materials, and hence is an important consideration in terms of material selection and the specification of components such as pipeline bends. In relation to particle degradation, it is equally important, for as the impact angle reduces, so the normal component of velocity decreases. This will have a direct bearing on the deceleration force on the particles. The results of a comprehensive program of tests carried with the 5-mm aluminium-oxide particles aimed at investigating the influence of particle-impact angle are presented in Figure 10 [*1*].

Figure 10 shows that there is little change in the response to degradation until the impact angle is below about 50 deg. There is then a very marked difference in performance, with only small incremental changes in impact angle. With a decrease in particle-impact angle, it would appear that there is little change in the particle velocity at which the onset of

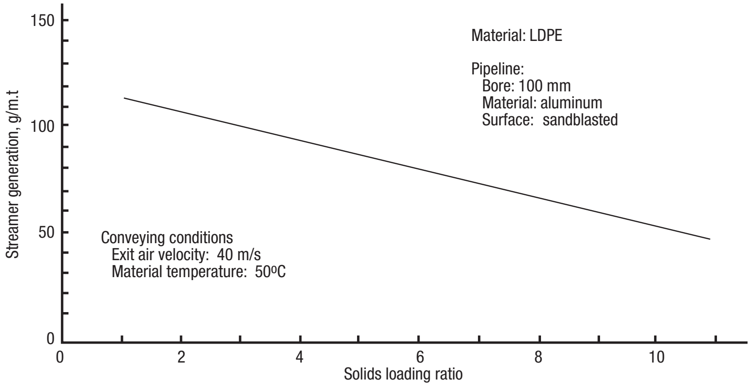


FIGURE 13. Solids-loading ratio can have an effect on the degradation of LDPE

degradation occurs. The transition from zero degradation to total degradation, however, becomes an increasingly more gradual process as the particle-impact angle decreases. At impact angles of 15 and 20 deg, it would appear that this transitional process is spread over a very wide range of velocity values. At an impact angle of 10 deg, however, there is a significant change once again, in that no particle degradation was recorded at all up to 30 m/s.

In Figure 11, an alternative plot of the data in this program of tests is presented. This is effectively a slice taken from Figure 10 at a particle velocity of 23 m/s. This graph shows that tests were carried out at regular increments of impact angle (about 10 deg) between 10 and 90 deg. This plot shows quite clearly that at impact angles below about 12 deg, no degradation occurs, and that at impact angles above about 55 deg, the degradation remains essentially constant at the maximum value for this particular impact velocity.

Particle melting

Particle melting is a form of material degradation that often occurs in pneumatic conveying plants handling plastic-type materials, particularly in pelletized form. If a conventional pipeline is used, materials such as polyethylene, nylon and polyesters can form cobweb-like agglomerates. They are variously given names like "angel hairs," "raffia," "snake skins" and "streamers."

Such agglomerates frequently cause blockages at line diverters and filters, which require plant interruption to remove them. Equipment is generally installed at the terminating end of the conveying system for this purpose. Such equipment is necessary because streamers also cause material rejection by customers (because the presence of these contaminants in the product is undesirable).

Mechanics of the process. The streamers are caused by the pellets impacting against pipe bends and "sliding" along the inside surface of the pipeline. A considerable amount of energy is converted into heat by the friction of the two surfaces when they touch. If the surface of the pipe is smooth, the pellet will slide. This contact, though momentary, decelerates the particle by friction, which is transformed into heat. This friction is generally sufficient to raise the temperature at the surface of the pellet to its melting point. To a certain extent, this is analogous to the thermal model proposed for erosive wear.

Influence of variables. The onset of the formation of these angel hairs or streamers is the result of a combination of conditions. Particle velocity is the most important, but it also depends upon the temperature of the pipeline, the temperature of the pellets, and the solids-loading ratio of the conveyed material. The influence of conveying-line exit-air velocity for low-density polyethylene is shown in Figure 12 [*5*].

The influence of solids-loading ratio for this same material is given in Figure 13. In each case, the degradation of the material is expressed in terms of the mass of streamers and fines produced, in grams, per metric ton of low-density polyethylene conveyed.

Pipeline treatment. The formation of streamers and fines can be reduced quite considerably by suitably treating the pipe wall surface. A roughened surface is necessary in order to prevent the pellets from sliding. If the surface is too rough, however, small pieces will be torn away from the pellets instead, and a large percentage of fines will result. It will also have an adverse effect on the pressure drop, and hence on material conveying capacity.

Although the results presented in Figures 12 and 13 were obtained from tests carried out with pipe surfaces roughened by sandblasting, this treatment is not recommended, as it will result in the generation of a large percentage of fines. Also, this roughness is relatively shallow in depth and an aluminium surface will wear so that the pipe must be retreated in six to twelve months.

A more recent innovation is to attach a small-diameter wire to the inner surface of the pipeline, arranged in a spiral. This essentially acts as a "tripwire" for any particles that are sliding. On impact with the wire, any particles impacting it will be thrown back into the conveying air flow. ■

Edited by Scott Jenkins

References

1. Mills, D., "Pneumatic Conveying Design Guide," 3rd Ed., Butterworth-Heinemann (Elsevier Ltd.), 2016.
2. Mason, J.S. and Smith, B.V., The erosion of bends by pneumatically conveyed suspensions of abrasive particles., *Powder Technology*, vol. 6, pp. 323–335, 1973.
3. Tilly, G.P., "Erosion caused by impact of solid particles. Treatise on materials science and technology," Academic Press Inc., vol. 13, pp 287–319, 1979.
4. Mills, D., Safety Aspects of Pneumatic Conveying. *Chem. Eng.*, April 1999, pp. 84–91. April 1999.
5. Paulson, J., Effective means for reducing formation of fines and streamers. presented at Process Conf. on Polyolefins, Society of Plastics Engineers, Houston, 1978.

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Designing Atmospheric Storage Tanks

Insights into the basics of process design of atmospheric storage tanks and an example of how to prepare a process datasheet are presented here

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Jacobs Engineering India

Storage tanks are widely used in the petroleum refining and petrochemical sectors to store a variety of liquids, from crude petroleum to finished product (Figure 1). This article presents the basic process of designing atmospheric storage tanks (ASTs), as well as a discussion about preparing a process datasheet. An example is used to illustrate the points made.

FIGURE 1. Storage tanks are a common sight at petroleum refineries and petrochemical plants

When to opt for ASTs

In simple terms, storage tanks that are freely vented to the atmosphere are known as (aboveground) atmospheric storage tanks (ASTs). They have a vertical cylindrical configuration and can be easily identified by the open vent nozzle or "gooseneck" vent pipe on the tank roof. ASTs may be shop-welded or field-welded and are customarily fabricated from structural quality carbon steel, such as A-36 or A-283 Gr.C. The vertical cylindrical shape and relatively flat bottom helps to keep costs low.

ASTs store low-vapor-pressure fluids that do not pose any environmental, hazard or product-contamination issues, so they can be freely vented to the atmosphere. However, when storing certain fluids, such as when vapors of the stored liquid are flammable or when oxidation of liquid may form hazardous compounds, it is undesirable to have the tank vapor space freely vented. In such cases, inert gas blanketing of the vapor space may be used. Tanks with inert-gas blanketing are also often included in this category. A blanketing system is normally designed so that it operates at slightly higher than atmospheric pressure, therefore preventing outside air from entering the vessel.

Typically, ASTs are considered to have an operating pressure ranging from 0 to 0.5 psig. Tanks designed to operate at pressures between 0.5 and 15 psig are termed as low-pressure storage tanks. Designs above 15 psig are treated as pressure vessels.

Tank roof types

There are two basic types of vertical-tank roof designs — fixed or floating roof.

Fixed roof. In this design, the tank roof is welded with the shell and the roof remains static.

Floating roof (internal or external). In this design, the tank roof floats on the liquid surface and rises and falls with changes in liquid level. The *internal floating-roof tank* (IFRT) has a permanent fixed roof with a floating roof inside while the *external floating-roof tank* (EFRT) consists of an open-topped cylindrical shell with a roof that floats on the liquid. An IFRT is used where heavy accumulation of snow or rainwater, or lightning is expected and may affect the roof buoyancy of an EFRT. In an IFRT, tank vapor space located above the floating roof and below the fixed roof includes circulation vents to allow natural ventilation of the vapor space, which reduces the accumulation of product vapors and possible formation of a combustible mixture. In some cases, the natural ventilation is avoided and the vent is either sent for treatment (for example, to a scrubbing tower) or to a vapor-recovery system (for example, a benzene-vapor-recovery system).

As a rule of thumb, fixed-roof tanks are used to store liquids with true vapor pressures (TVP) of less than 10 kPa(a) (TVP is the absolute pressure when the vapor is in equilibrium with liquid at a constant temperature). Floating roofs are limited to storing liquids with a maximum TVP of 75 kPa(a). For liquids with flash point (the lowest temperature, corrected to a barometric pressure of 101.3kPa(a), at which application of a flame test causes the vapor of the test portion to ignite under the specified conditions of the test) below 37.8°C, excessive loss of volatile liquids occurs from the use of open-vented fixed-roof tanks. Hence, floating roofs are mostly used for liquids with flash points below 37.8°C.

Codes for tank design

The American Petroleum Institute (API; Washington, D.C.; www.api.org) has developed a series of atmospheric tank standards and specifications. Some of these are: API Specification 12B, API Specification 12D, API Specification 12F, API Standard 2000, API Standard 650, API Standard 620. The ASME Boiler and Pressure Vessel Code, Section VIII, although not required below 15 psig, may also be useful.

BS EN 14015 is used in Europe, along with other codes, such as BS EN 13445, PED, SEP, KIWA and others.

The two main API codes used for tank design are API 650 and API 620 (Table 1).

For different fluid groups, the type of storage and the appropriate design code to be followed can be found in Ref. 1.

Calculation design basis

Before starting the sizing calculations, a calculation design basis is prepared that provides a back-up of all the information used in the process design of the storage tank. In most engineering companies, this document is a must, and is prepared to understand the source of data and to keep traceability of data used in the design. Typically, it contains details like the following:

1. The equipment tag number
2. Objective of design (for example, to calculate the dimensions of the tank T-1001; to set level alarms and so on)
3. Basis of design (notes like: HHLL (high high liquid level) is set at an elevation above HL to permit an operator time response of 20 min)
4. Assumptions (for instance, a maximum capacity utilization of 90% is assumed)
5. Actual calculations
6. Sketches
7. Results or conclusions
8. Reference documents
9. Attachments.

Sizing ASTs

Typically, tank capacity is given in the process part of a basic design and engineering package (BDEP) directly as the process volume required or indirectly as the residence time (for example, hours or days of storage of product or raw material feed). At times, the number of tanks and their preliminary dimensions (diameter × height) may also be mentioned.

TABLE 1. API 650 AND API 620 DESIGN LIMITATIONS

Standard	Internal design pressure limit (psig)	External design pressure limit (psig)	Internal design temperature limit (°C)	Other limitations
API 650	≤ 2.5	≤ 0.03625	≤ 93	1. When using API 650 for pressures exceeding 2.5 psig (internal), 0.036 psig (external) but not exceeding 1 psig and temperatures greater than 93°C but not exceeding 260°C, requirements given in the associated annexures needs to be met. 2. Different specifications (ASTM,CSA, ISO, EN for plates) suggested for carbon steel, low-alloy carbon steel, structural steel, killed carbon steel and so on. The material of construction used shall conform to the specifications given in API 650. To design tanks with stainless steel and aluminium, Annex S & AL needs to be followed respectively[1]
API 620	2.5–15	Not applicable[2]	≤ 121.1 and –45.5	For other low temperature limitations refer to Appendices Q, R & S[1]

Notes:

1. Plate materials [*4*] are given in both API 620 & 650.

2. API 620 does not contain provision for vacuum design. However, vertical tanks designed in accordance with API 620 may withstand a partial vacuum of 0.0625 psig in the vapor space with the liquid level at any point from full to empty.

Dimensions of a storage tank really depend on the process requirement and needs of the client. For a given inflow rate, the tank dimensions will vary based on the amount of time the tank is designed to hold the contents. Also, based on the storage capacity and vapor pressure of the stored product, certain regulatory requirements may govern the type of tank to be used, for example, Standard 1910.110-Storage and Handling of Liquefied Petroleum Gases by OSHA regulations of U.S.

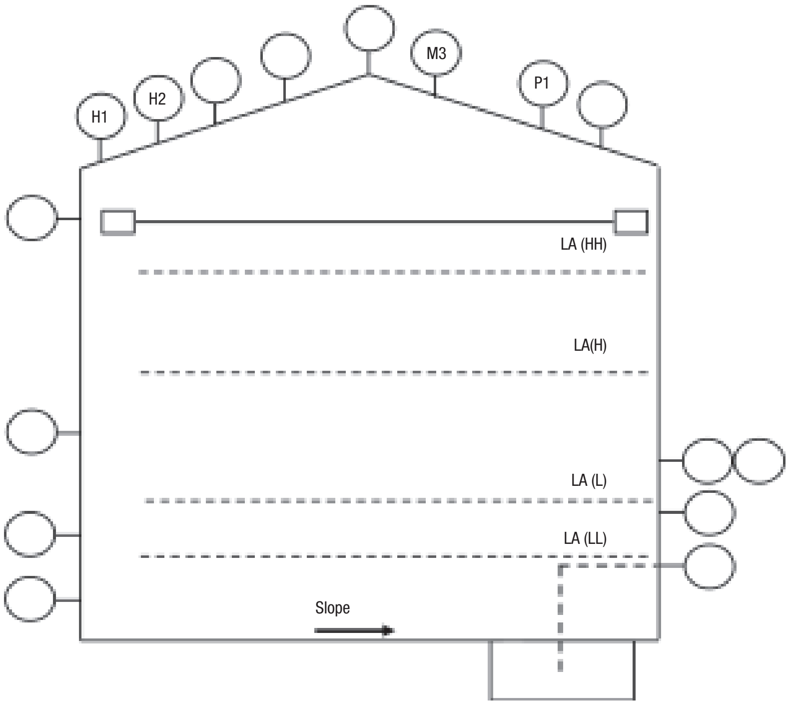


FIGURE 2. **This preliminary sketch of an AST also shows the relative positions of the alarm levels (LAs) defined in the text**

A tank is a compound geometric form, such as a combination of cylindrical shell and conical roof. However, it should be noted that the net volume and the maximum volume mentioned in the process datasheets are calculated only for the cylindrical shell. The tank head volume is never considered in the storage tank process-volume calculation.

The purpose of storage is based on varied process functional requirements, including the following:

- ***Product storage tank*** — To store chemical inventory produced in a plant
- ***Spare tank*** — For temporary storage of fluid until inspection or maintenance of working tank is completed
- ***Off-specification tank*** — To store product deviated from normal specifications until it is re-processed
- ***Check tank*** — To verify or sample raw material, intermediate or product quality before its use or transfer
- ***Day tank*** — For fuel-oil supply to diesel generators and dual-fuel boilers

Calculating the tank volume

As an example, a storage tank will be designed using the following known data:

- To store, for 30 h, light off-specification olefin (C6, C8, C10) production
- Working volume to gross volume ratio = 0.7 (for IFRT, this needs to be ≤0.9)
- The highest inflow rate to the tank is 57.5 gal/min
- Vapor pressure at operating temperature = 41.3 kPa(a)
- Tank has a 2-in. pump-out nozzle and 6-in. jet-mixer nozzle

In this case, because the TVP is greater than 10 kPa(a), we opt for an internal floating-roof tank.

We have gathered storage time and tank volume ratio (0.7) from the process part of the BDEP and the tank inflow rate and vapor pressure from a heat and material balance (H&MB) table.

Process volume = (Maximum inflow × time)
= 57.5 gal/min × 30 h × 60 min/h
= 103,500 gal (~392 m^3)

Tank volume required = (Process Volume) ÷ 0.7
= 103,500 ÷ 0.7
= 147,857 gal (~560 m^3)

TABLE 2. ESTIMATING TANK DIMENSIONS					
Steel plate course	**Tank diameter**	**Capacity per m of tank height**	**Required tank height**	**Number of courses in completed tank**	**L/D ratio**
(mm)	(m)	(m^3)	(m)	–	–
1,800	9	63.6	9	5	1
2,400	9	63.6	9.6	4	1.07

Therefore, the volume that will be stored in the tank is calculated to be 147,857 gal (approximately 560 m^3).

Selecting tank dimensions

As a starting point to estimate the correct preliminary dimensions (diameter and height) by trial and error, a process engineer can refer to as-built plant data, such as a storage tank process datasheet; an equipment list; or a general assembly drawing. This will at least give a fair idea of initial values of the diameter and height to be used for trial and error.

Alternatively, typical volume versus dimensions table provided by a tank fabricator can be used, or tables for typical sizes and corresponding nominal capacities (for example, as given in Appendix A of API 650 [*2*]). These appendix tables readily provide the tank height and number of courses (number of rows of steel plates stacked) for a given tank diameter. However, all the requirements mentioned in Appendix A need to be met.

Using the tables given in Appendix A of API 650 [*2*], we obtain the results tabulated in Table 2. For calculated tank volume and a diameter of 9 m, we can obtain two different configurations with (diameter × height × number of steel plate courses) as (9 × 9 × 5) or (9 × 9.6 × 4). The height-to-diameter ratio (*L/D*) for these two configurations will be 1 and 1.07, respectively. Both the *L/D* ratios calcu-

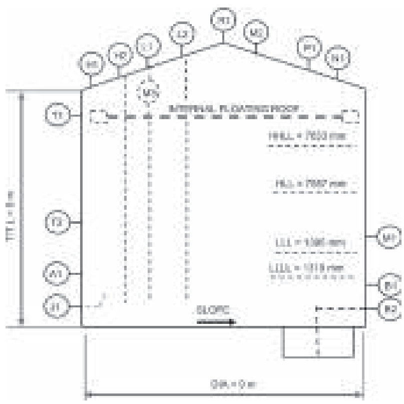
TABLE 3. SETTING TANK ALARMS			
Tank height (*L*)	–	9,000	mm
Tank diameter (*D*)	–	9,000	mm
L/D	–	1.00	-
Geometric volume	–	572.27	m^3
Tank filling rate	–	57.5	gpm
Center line of 2-in. pump out nozzle from tank bottom (regular nozzle) [*3*]	–	175	mm
Tangent to the top of pump out nozzle = height of center line of pump out nozzle + (O.D. of pump out nozzle)/2 in.	= 175 + (60.3/2)	205.15	mm
Center line of 6-in. jet mixer nozzle from tank bottom (regular nozzle) [*3*]	–	306	mm
Tangent to the top of of jet mixer nozzle inside the tank bottom = height of center line of jet mixer nozzle + (O.D. of pump out nozzle)/2	= 306 + (168.3/2)	390.15	mm
Clearance between floating roof and top of jet mixer	~ 4 in.	100	mm
Elevation at the tip of mixer nozzle inside the tank (assumed)	~ 4 ft	1,219	mm
Low low liquid level (LLLL)	–	1,319	mm
Height between LLLL and LLL	~ 3 in.	76	mm
Low liquid level (LLL)	–	1,395	mm
Process volume	–	392	m^3
Height corresponding to process volume	= process volume / [0.785 × (dia.)]^2	6,161.67	mm
High liquid level (HLL)	–	7,556.67	mm
Time gap to fill the height between HLL and HHLL			
(Considering time for operator intervention)	-	20	min
Height between HLL and HHLL (calculated)	= (Time to fill the height between HLL & HHLL × tank filling rate) / [0.785 × (dia.)^2]	68.43	mm
Height between HHLL and HLL	~ 3 in.	76	mm
High high liquid level (HHLL)	–	7632.67	mm
Free space above HHLL (minimum 500 mm)	= Tank height – HHLL	1,367.33	mm
Percentage of filling achieved	= HHLL/tank height	0.85	%

TABLE 4. EXAMPLE PROCESS DESIGN SHEET

Row No.	Storage tank process datasheet		Rev	Issued for	Date	Made by	Checked	Approved
1	**Client:** A1 Chemical Company	**Tag No.:** T-1001	A	Prelim-inary	1-Jan-16	KEPR	SISA	KOQU
2	**Project:** Perfect project	**Job No.:** 820918						
3	**Location:** Houston							
4	**Service:** To hold off-specification batch of olefin material							
5	**No. required:** one (1) I.D.: 9 m	Height: 9 m Orientation: Vertical						

Row No.						
6	**Design conditions**					
7	Internal pressure: (Opt.):		0.0361 psig	Design:	0.2167	psig
8	External pressure: (Opt.):		ATM	Design:	0.0625	psig
9	Operating temperature:		110°F	Design:	150	°F
10	Liquid stored: Light olefin (C6, C8, C10)					
11	Specific gravity (Max.): 0.72 at 110°F					
12	Capacity (Working/Max.):		103,500	gal	147,857	gal
13	Roof type: (fixed/floating): Internal floating roof					
14	Blanket gas: Nitrogen		Vapor pressure @T_{max}: 6 psi(a)			
15	Code: API 650		Stamp: yes			
16	Radiography: (1)		Efficiency: (1)			
17	Hydrotest:(shop/field): (1)					
18	Stress relieve: (1)					
19	Mag. particle: (1)			Dye penetrant: (1)		
20	Windload: (1)			Earthquake: (1)		
21	Weight (empty/full): (1)					
22	**Materials of construction**					
23	**Component**	**Basic material**		**Corrosion allowance** (in.)		
24	Shell	Killed carbon steel (2)			1/16	
25	Roof	Killed carbon steel (2)			1/16	
26	Nozzle-MH / flanges	Killed carbon steel (2)			1/16	
27	Floor	Killed carbon steel (2)			1/16	
28	Boot	Killed carbon steel (2)			1/16	
29	Lining:	N.A.				
30	Gaskets:	(1)				
31	Bolting:	(1)				
32	Internals:	Internal floating roof (3), jet mixer (4)				
33	Roof support:	(1)				
34	Paint:	(1)				
35	Insulation:	N.A.				
36	**Accessories**					
37	Insulation rings		N.A.			
38	Davit		(1)			
39	Pipe support rings		(1)			
40	Ladder and platform clips		(1)			
41	Internal piping		(1)			
42	Fire proofing clips		(1)			
43	Agitator		N.A.			

Sketch



continued on next page

lated in Table 2, are acceptable.

In general, tank heights do not exceed 1.5 times the tank diameter. As the tank height increases, the wall thickness increases and a bigger load is imposed on the soil, thus requiring heavier foundations. Often, for very large diameter tanks, *L/D* is kept less than 1, leading to squatter tanks. From a fire-fighting point of view, the maximum tank height considered is 20 m. Tank diameters are standardized based on shell-plate lengths, but tank heights are never standardized. To obtain an economical unit, it is the tank manufacturer who will choose the number of courses and plate widths to obtain the height required for a given diameter. Hence, a process or mechanical design engineer does not necessarily specify the number of shell-plate courses. The shell-plate sizes are generally kept as large as possible and within available standard sizes so as to reduce the length of welded seam, loss of plate material, amount of edge preparation and the degree of handling during erection. Shell heights are typically rounded off to the nearest meter and as far as possible, standard diameters are used. For this discussion, we will consider an *L/D* of 1 and proceed with our design.

The initial dimensions quickly obtained from the table may be used

TABLE 4. (CONTINUED)

44	**Nozzle Schedule**								
45	**Mark**	**Size**	**Flange rating/face**	**Service**	**Mark**	**No.**	**Size**	**Flange rating/face**	**Service**
46	A1	4	RF/150#	Feed	R1	1	Hold 1	RF/150#	RVVB
47	B1	2	RF/150#	Outlet	P1	1	2	RF/150#	Pressure tap
48	B2	2	RF/150#	Sump outlet	T1	1	1.5	RF/150#	Temperature element
49	H1	20 (Hold 1)	RF/150#	Emergency vent	T2	1	1.5	RF/150#	Temperature indicator
50	H2	4	RF/150#	Gage hatch					
51	J1	6	RF/150#	Jet mixer					
52	L1	6	RF/150#	Level transmitter					
53	L2	6	RF/150#	Level transmitter					
54	M1	24	RF/150#	Shell manway					
55	M2	20	RF/150#	Roof manway					
56	M3	24	RF/150#	IFR manway					
57	N1	4	RF/150#	Nitrogen					
58	Notes:								
59	1. Data by the mechanical-vessels group.								
60	2. Material grade by the vessels group.								
61	3. Internal floating-roof details by storage-tank vendor.								
62	4. For details, see let mixer datasheet (Ref. Doc.: J-1001-PDS, Rev. A).								
63	5. Nozzle A1 and B1 to be located on opposite sides of shell.								
64	6. Nozzle N1 and H1 to be located on opposite sides of roof.								
65	7. Suitable vacuum breaker (breather valve on rim vent) to be provided on roof when it rests at minimum.								
66	8. The roof supports should be adjustable for minimum operating level from bottom and minimum level for manual cleaning.								
67	9. Nozzles H2, L1 and L2 to be provided with stilling wells.								
68									
69	Holds								
70	1. To be confirmed during detailed engineering.							ATM = Atmosphere	
71	2. Instrumentation group to confirm all instrument nozzle sizes.							N.A. = Not applicable	

for cost-estimation at a very early stage of the project. However, the dimensions of the tank need to be firmed out as the project progresses in design phases. Firming up a tank dimension or tank sizing involves checking the following three steps:

1. Accommodate process volume or the working volume in the tank.
2. Set tank overfill protection level requirement (to permit operator response).
3. Set minimum operating volume in the tank.

Setting alarms

The overfill-protection volume and the minimum-volume allocation can be best understood in terms of level alarm (LA) values stated in the datasheet. Typically, four types of alarms are set at the following levels (see Figure 2 and Table 3):

- LLLL — low low liquid level
- LLL — low liquid level
- HLL — high liquid level
- HHLL — high high liquid level

Usually, levels are set above some point of reference in the tank. First, LLLL is set. It is the lowest liquid level below which the operation and safety may be affected; for example, to provide sufficient NPSHA (net positive suction head available) for the pump, or to avoid surface dry-out of the tank's internal heating coils. In most cases, the tangent to the top of the tank-outlet nozzle is considered as the LLLL alarm. Above the LLLL, some buffer volume is provided until LLL, to avoid disturbing the process volume due to draw-out by the pump. Above LLL, the height equivalent to process volume is then accommodated to reach HLL. To prevent overfill of the tank, an operator-intervention time of 20 minutes is considered and a height corresponding to this volume, or a minimum of 3 in., is added above HLL to attain HHLL. As a minimum, HHLL should be set at least 500 mm below top of the tank.

For a fixed-roof tank, as explained, we consider LLLL = 205.15 mm (at the tangent of 2 in. pump out nozzle) and then set the remaining alarms starting from this point.

However, for an IFRT that also has an internal jet-mixer nozzle, we have an additional approach to fix the levels. We evaluate tangent to the top of the jet mixer nozzle as 390.15 mm. As a good engineering practice, LLLL is set such that: 1) there is a minimum clearance of at least 4 in. between the internal floating roof and any internal parts, such as jet mixer nozzle; and 2) the roof remains floating with its supports at least 4 in. above the tank bottom. Also, based on experience, it is assumed that the elevation at the tip of the mixer nozzle inside the tank is 4 ft. Thus, the LLLL is set at an elevation at the tip of the mixer nozzle plus the minimum clearance between the internal floating roof and the jet mixer nozzle at 1,319 mm. LLL is then set 3 in. above LLLL.

Preparing the tank datasheet

Once the sizing is done, we move to preparation of the tank datasheet. The datasheet may be considered as the owner's permanent record for describing a tank, and it is used to make proposals and place subsequent contracts for fabrication and erection of the tank. This section explains the information to be placed in the datasheet by the process engineer.

General instructions. This set of instructions are of a basic nature, but nevertheless are equally important as the detailed technical instructions. Also, they are commonly followed in most engineering companies.

- Use the correct, applicable and latest datasheet template
- In no case should a line in a datasheet be left blank. If you don't have data for a particular parameter or it is not applicable, please put a dash or write "N.A." (not applicable), respectively
- Marking N.A., "TBC" (to be confirmed), "later" or other such terminology can be used. It should, however, be stated clearly in the datasheet what this terminology means
- Every numerical entry should be correct and have appropriate units stated. If a value is repeated (for example, dia. in the datasheet and sketch), it should be updated at both places in case of any revision
- Document revision status should be correctly entered, for example: typical revision status entries include for quotation, bid, for design review, for design revision and as-built
- Document revision number should be correctly entered, for example: 1, 2, 3 or A, B, C or A1, A2 and so on
- Engineering notes and holds should be given at the end of the datasheet and their reference in the datasheet should be given at the correct place
- Sheet numbering should be correctly done (for instance, sheet 1/5)
- Once the datasheet is prepared, it should pass checking and approval cycles. Only then can it be issued for release

Technical part. The process data entered in the API 650 datasheet is filled in by the process engineer, and the mechanical data portion is completed by the mechanical engineer. For instance, data like operating and design conditions, liquid density and vapor pressure, tank diameter and height, tank sketch, basic material of construction, nozzle schedule and so on are provided by a process engineer. Conversely, a mechanical engineer supplies data like shell design method, plate width and thickness, plate stacking criteria, joint efficiency, nondestructive examination (NDE), positive material identification (PMI) design requirements and so on.

Some engineering companies maintain a single process datasheet template that is created to contain only the data under process scope. This may be filled by the process engineer and passed on to the mechanical engineer who may then use it to complete an API 650 datasheet or fill a mechanical datasheet template to be used along with process datasheet.

For the sake of discussion, we consider a simplified tank datasheet template to be filled by a process engineer, shown in Table 4. This example datasheet can be broken down as follows:

Rows 1–3. Enter all identification data and fill the revision table.

Rows 4–5. Refer to process description and PFD to enter the service, number of tanks required and orientation. Tank dimension values to be given from the calculation.

Rows 7–11. Operating conditions, liquid stored and specific gravity can be filled referring to PFD and H&MB stream data. Design conditions are to be filled using process part of BDEP or using DP/DT (design pressure/temperature) diagrams. If the tank stores multiple liquids (as applicable in this case), then state the highest specific gravity of the liquid at operating temperature.

Rows 12–13. Enter the capacities from calculation (Working capacity (from LLL to HLL) and maximum capacity (from bottom to HHLL)). Roof type can be entered by referring to the PFD and/or process part of the BDEP.

Row 14. Refer to the process description and PFD and enter the data for blanketing gas and vapor pressure.

Rows 15–21. Data in these rows will be filled by the mechanical-vessels group. Write note 1.

Rows 24–28. State the basic minimum material of construction. The correct grade will be specified by the mechanical engineer. Write note 2. If an alloy material is used, state the type specifically (for example, do not write SS only, but write SS 316, and so on). The corrosion allowance is to be given by referring to the process part of the BDEP.

Row 29. Lining is not required in this case, so write N.A.

Rows 30–31. Data in these rows will be filled by the mechanical-vessels group. Write note 1.

Row 32. State applicable tank internals. For the jet mixer, the details like material, number, dimensions, flowrate, angle and so on, can be given in the datasheet itself or a reference of a separate datasheet may be given. Write notes 3 and 4.

Row 33–34. Data in these rows will be filled by the mechanical-vessels group. Write note 1.

Row 35. Insulation is not required in this case, so write N.A.

Row 37. Not required in this case, so write N.A.

Rows 38 and 42. Data in these rows will be filled by the mechanical-vessels group. Write note 1.

Row 43. Not required in this case, so write N.A.

Rows 46–57. Fill the nozzle schedule by referring to the P&ID, PFD, process description and calculations, as well as the process part of the BDEP. The process nozzles A1, B1, B2, N1 and R1 require actual sizing. A1 is to be sized based on the maximum inlet-liquid flow, B1 and 2 are sized using rated pump flow and pump-suction line-sizing criteria. Using inbreathing calculations N1 can be sized. R1 and H1 sizes to be confirmed later during detail engineering. Instrument, vent and manway sizes will be filled using project design basis.

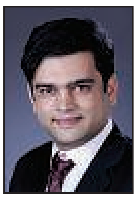
Finally, make a simple tank sketch showing the dimensions, correct nozzle tags and positions required, alarm levels and all internals dotted. ■

Edited by Gerald Ondrey

References

1. "GPSA Engineering Databook," 12th ed, Section 6 – Storage, Figure.6–2: Storage, 2004.
2. API 650, 12th ed., March 2013, Annex A, Tables A.1a and A.3a.
3. API 650, 12th ed., March 2013, Section 5 – Design, Table 5.6a.
4. API 650, 12th ed., March 2013, Section 4 – Materials, Table 4.4a-

Author



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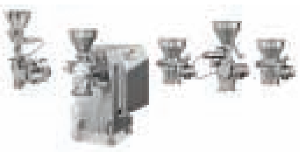

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Key Considerations in Specifying Control Valves

Follow this guidance to specify a control valve accurately during the design phase

Satyendra Kumar Singh
Simon India Limited

Control valves are one of the most common and important instruments used in the chemical process industries (CPI). They help to ensure smooth and efficient operation of process plants, by achieving the desired operating parameters by means of regulating the fluid flow in connected pipes. The need to properly specify control valves during the design phase of a plant cannot be overemphasized.

The size of a control valve is derived from a parameter called the flow coefficient (C_V), which is defined as volumetric flowrate (in gal/min) of water through the valve at 60°F when pressure drop across the valve is 1 psi (C_V is calculated using the formula given in the standard ISA-75.01.01-2007). Process engineers should take the following aspects into consideration when specifying control valves, to ensure that the valves that are manufactured by the vendors function according to the requirements.

1. Controllability. While specifying a control valve during the design phase, the process engineer should ensure that the valve's controllability must be good over the entire range between minimum and maximum flowrates. This can be done by estimating the maximum C_V and minimum C_V that correspond to maximum flowrate and minimum flowrate, respectively. In general, the controllability of a control valve is deemed acceptable if its travel at maximum flowrate does not exceed 90% of the rated travel, and if travel at minimum flowrate is in the range of 10–20% of the rated travel. This means the ratio of estimated maximum C_V to estimated minimum C_V should preferably not be more than 15. If the ratio far exceeds this value, travel at minimum flow may be less than 10% of the rated travel, or the travel at maximum flow may be greater than 90% of the rated travel — both scenarios mean poor controllability of the valve. In that case, pressure drop across the control valve should be increased so that the target ratio can be lowered, as shown in Equation (1). For incompressible fluids, the ratio of maximum C_V to minimum C_V is given by Equation (1):

$$(C_V)_{max}/(C_V)_{min} = (\max flowrate/\min flowrate)(\Delta P_{min}/\Delta P_{max})^{0.5} \quad (1)$$

Figure 1 shows a typical control valve circuit. The following notes add further explanation:

i. The segments represented by P_1A and BP_2 represent items connected to the valve (such as pipes, fittings, heat exchangers, flow elements, and more), whereas the segment represented by AB represents the control valve in the complete circuit P_1ABP_2. The arrows in this circuit represent flow direction.

ii. ΔP denotes pressure drop.

iii. Indicated pressure drops are for maximum flow.

Referring to Figure 1, if x is the pressure drop across the control valve circuit P_1ABP_2, and y is the pressure drop across the control valve AB for maximum flow, then the pressure drop in the remaining part of the circuit (consisting of the pipes, fittings, heat exchangers, flow elements and more; as represented by the segments P_1A and BP_2) is $x–y$ for maximum flow.

If r is the ratio of maximum to minimum flow, and z is the pressure drop across the circuit P_1ABP_2 at minimum flow, then — ignoring the elevation difference between P_1 and P_2 — pressure drop in the part of the circuit other than the control valve (that is, P_1A and BP_2) at minimum flow is approximately $= (x–y)/r^2$.

Pressure drop across the control valve AB at minimum flow is approximately:

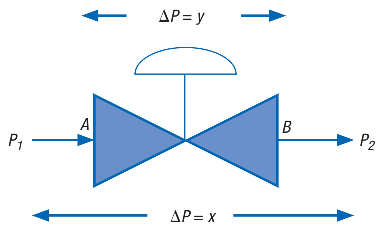

FIGURE 1. Shown here is a typical control valve circuit, which is used illustratively in the descriptions provided in the main text

$$= z-(x-y)/r^2 \quad (2)$$

From Equation (1) and Equation (2), $(C_V)_{max}/(C_V)_{min}$ is approximately:

$$= r\left[\left(z-(x-y)/r^2\right)/y\right]^{0.5}$$

$$= \left[1+\left(zr^2-x\right)/y\right]^{0.5} \quad (3)$$

The following conclusions can be drawn from Equation (3):

iv. As r>1 and z≥x, any increase in y leads to decrease in the ratio $(C_V)_{max}/(C_V)_{min}$. That is, better controllability can be achieved by increasing pressure drop across the control valve at maximum flow. (Note: $z = x$ if P_1 and P_2 are fixed pressure points, and in general $z>x$ if the control valve is located at the discharge of a centrifugal pump

v. If r increases, y also increases for the same ratio of $(C_V)_{max}$ to $(C_V)_{min}$. This means that pressure drop across the control valve at maximum flow should increase with an increase in the ratio of maximum to minimum flow, if the same controllability has to be achieved.

vi. In most common cases, maximum flow is 110%, and minimum flow is 50%, of normal flow. In such cases, if pressure drop across the circuit P_1ABP_2 remains same for maximum and minimum flows, then Equation (3) becomes the following:

$(C_v)_{max}/(C_v)_{min}$ is approximately = $[1 + (3.84x/y)]^{0.5}$, which implies that $(C_v)_{max}/(C_v)_{min}$ is approximately 3.5, for an x/y value of 3.0. A $(C_v)_{max}/(C_v)_{min}$ value close to 3.5 corresponds to reasonably good controllability. Hence, it can be said that for good controllability, pressure drop across the control valve should be approximately one third of total dynamic pressure drop across the circuit at maximum flow, if maximum and minimum flow are 110% and 50%, respectively, of normal flow.

Although Equation (3) is true for incompressible fluid, the above results in general are reasonably true for compressible fluid, as well.

2. Cavitation. When fluid is flowing through a control valve, the minimum pressure occurs at the *vena contracta*, and then pressure increases along the path of flow until the fluid reaches the outlet of the control valve. The *vena contracta* is the point in the flow path where the flow area is minimum, the velocity is maximum and, hence, pressure is minimum [*1*]. For liquids, if the pressure at the *vena contracta* is less than the vapor pressure of the liquid, vapor bubbles will form. Downstream of the *vena contracta*, pressure recovery takes place, resulting in higher pressure at the valve outlet than at the *vena contracta*. If pressure at the outlet of the control valve exceeds the vapor pressure, the vapor condenses and bubbles collapse. As bubbles collapse, it causes impact on the valve body and creates noise. This phenomenon is called cavitation.

Full cavitation occurs when pressure drop across the control valve is more than or equal to certain minimum pressure drop (or critical pressure drop), and the pressure at the outlet of the control valve is more than the vapor pressure of the liquid. Thus, full cavitation occurs if the following conditions are met [*2*]:

$$\Delta P \geq F_L^{\,2}\left(P_1 - F_F P_V\right) \quad (4)$$

$$\Delta P = P_1 - P_2$$

Where:

P_1 = Absolute pressure at the inlet of the control valve

P_2 = Absolute pressure at the outlet of the control valve

F_L = Liquid pressure-recovery factor, as defined by:

$$F_L = \left[(P - P_2)/(P_1 - P_{VC})\right]^{0.5}$$

P_{VC} = Absolute pressure at the *vena contracta*

F_F = Liquid critical pressure ratio factor

$F_F = 0.96–0.28\,(P_V / P_C)^{0.5}$

P_c = Absolute thermodynamic critical pressure of the liquid

P_v = Absolute vapor pressure of the liquid at inlet temperature

The exact value of F_L for a particular valve can only be available in the valve vendor's specifiction sheet, but an indicative value can be obtained from the vendor catalog, from ISA-75.01.01-2007, or from other control valve literature during the design phase.

Process engineers should try to minimize the possibility of cavitation when specifying control valves. This can be done in the following ways:

i. Alter the hydraulics of the control valve circuit and reduce the pressure drop across the control valve to less than $F_L^2(P_1 - F_F P_V)$, where possible (as explained above), without compromising the controllability of the valve.

ii. Try to change the location of the control valve such that the possibility of flashing through the control valve can be avoided. For example, if a liquid is being heated in an exchanger in the control valve circuit, the control valve should be located upstream of the exchanger — not downstream — so that vapor pressure of the liquid is sufficiently less than the operating pressure at the *vena contracta* of the control valve. This will eliminate flashing through the control valve.

iii. Locate the control valve in the circuit where the elevation is minimum so that static head is maximum. This will maximize P_1 as well as P_2 without impacting $(P_1–P_2)$. That can make the left-hand term in Equation (4) less than the right-hand term and, hence, prevent cavitation.

iv. Select a control valve body type with higher pressure-recovery factor (F_L), which makes critical pressure drop for cavitation — that is, $F_L^2(P_1 - F_F P_V)$ — higher. For example, a globe valve has a higher F_L than that of butterfly and ball valves. Thus, the use of a globe valve (instead of a butterfly or ball valve) might prevent the cavitation.

It is absolutely necessary to specify the thermodynamic critical pressure and vapor pressure of the liquid in the process datasheet of a control valve handling a liquid, so that the occurrence of the cavitation can be assessed. Full cavitation results in choked flow and happens if $\Delta P \geq F_L^2\,(P_1–F_F P_v)$. However, partial cavitation can occur

TABLE 1: COMPARISON OF VARIOUS TYPES OF CONTROL VALVES [*1*]

Parameter	Type of the control valve		
	Butterfly valve	Ball valve	Globe valve
Cost	Low	Low	High
Pressure drop	Low	Low	High
Flow capacity	High	High	Low
Flow characteristic	Fixed (approximately equal percentage)	Fixed. For V-notch ball valve, flow characteristic is equal percentage	Any of the three (linear, equal percentage, quick opening), depending on plug or cage design
Liquid pressure recovery factor (F_L)	Low	Low	High
Cavitation potential	High (due to low F_L)	High (due to low F_L)	Low (due to high F_L)
Noise potential	High	High	Low. Can be reduced further by using cage guided plug
Control range	Low	In-between for V-notch ball valve	High
Control type	Throttling and on-off	On-off. However, V-notch ball valves have good throttling capability, too	Throttling
Rangeability	Low	V-notch ball valves have very high rangeability	High

without causing choked flow, if pressure drop is less than critical pressure drop but greater than $\Delta P_{incipient\ cavitation}$ [2], where:

$$\Delta P_{incipient\ cavitation} = K_C\left(P_1 - F_F P_V\right)$$

Where:
K_c = The coefficient of incipient cavitation, which is less than F_L [2].

3. Multiple operating cases. Whereas a control valve is generally specified for three cases — minimum, normal and maximum flowrates, with corresponding pressure drop — there may be more than three operating cases. In such situations, normal flowrate and corresponding pressure drop should be specified in accordance with the normal operating case, whereas other operating cases (if there are more than two) should be narrowed down to two cases. When narrowing down the operating cases, C_v should be estimated for each case. Then, minimum and maximum flowrates (and corresponding pressure drops) should be specified in such a way that they correspond to the minimum and maximum C_v of the control valve, and the C_v corresponding to all other cases should lie between minimum C_v and maximum C_v. As actual C_v is not available when a control valve is specified, the estimated C_v should be used.

4. Selection of type of valve. Butterfly valves, which are compact and generally have a relatively low cost, are often the first choice. However, constraints may dictate otherwise. For instance, if high pressure drop across the valve is required, a globe valve may be the better choice. Because the resistance of a globe valve is higher than that of a butterfly valve, higher pressure drop can be obtained across a globe valve with reasonable size.

In liquid applications, high pressure drop could lead to cavitation. As the pressure-recovery factor of globe valves tends to be higher than that of other valve styles, cavitation can often be avoided with the use of globe valves.

In the case of gases, high pressure drop could lead to choking flow conditions, which can generate excessive noise. Noise can be minimized with a globe valve with the use of cage-guided trim. However, if the available pressure drop across the valve is low, then a butterfly valve may be the preferred choice.

Meanwhile, V-notch ball valves can be preferred where high rangeability is required. Standard, round-ported ball valves are generally used for on-off applications. Table 1 provides valve-selection guidelines.

5. Leakage class. The allowable control valve seat leakage is specified in terms of ANSI/FCI 70-02-2006 leakage class. This standard recognizes six classes of allowable seat leakage (Class I, II, III, IV, V and VI). Class I means highest allowable leakage; Class VI means least allowable leakage [3]. Generally, control valves for CPI applications are specified with leakage Class IV. However, in situations where tight shutoff is required, at least Class V should be specified. If a control valve is discharging to a flare, or is controlling (on-off) fuel flow to the burner of a fired heater or furnace, it should be specified with Class VI leakage.

6. Flow characteristics. The most common types of inherent flow characteristics are the following [1]:

- *Linear* — A valve with an ideal linear inherent flow characteristic produces a flowrate that is directly proportional to the amount of valve plug travel, throughout the travel range.
- *Equal percentage* — Ideally, for equal increments of valve plug travel, the change in flowrate regarding travel may be expressed as a constant percent of the flowrate at the time of the change.
- *Quick opening* — A valve with quick-opening flow characteristic provides a maximum change in flowrate at low travel rates. A quick-opening characteristic is basically linear through the first 40% of valve plug travel (corresponding to 70% of maximum flowrate), and there is little increase in flowrate with further increase in plug travel.

The flow characteristic of a valve depends on its trim design. While ball valves and butterfly valves have fixed characteristics, globe valves can have any of the three characteristics, depending on plug or cage design.

The type of flow characteristic should be specified in the process datasheet, considering the parameter to be controlled, or the pressure drop scenario in the system. For flow or level control, linear characteristic should generally be specified. In general, linear characteristic should also be specified if most of the pressure drop (as a proportion of total pressure drop in the system) is across the valve itself so that pressure drop across the valve remains nearly constant for varying flowrates. Equal-percentage characteristic should be specified for pressure control, or where a high proportion of the total pressure drop occurs in the system other than the valve (that is, in pipes, fittings, equipment and so on). It should also be specified where pressure drop across the valve varies with varying flowrate. A quick-opening characteristic should be specified for on-off applications. As in most of the common systems, pressure drop across the control valve varies significantly with flowrate, so equal-percentage flow characteristics are most commonly specified [1]. ■

Edited by Suzanne Shelley

References

1. Emerson Process Management, "Control Valve Handbook," 4th Ed., p. 18, pp. 33–36, p. 46, pp. 59–60, pp. 109–110, p. 136.
2. "Masoneilan Handbook for Control Valve Sizing," 7th Ed., pp. 7–8, p. 10, 1987.
3. American National Standard, Control Valve Seat Leakage, ANSI/FCI 70-2-2006, Cleveland, Fluid Controls Institute, Inc., p. 2, 2006.

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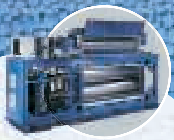

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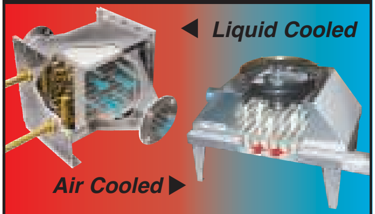

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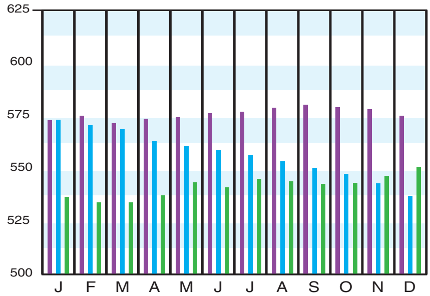
CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957-59 = 100)	Dec. '16 Prelim.	Nov. '16 Final	Dec. '15 Final
CE Index	550.8	546.6	537.0
Equipment	660.9	654.1	641.1
Heat exchangers & tanks	573.7	567.6	556.0
Process machinery	667.1	663.5	649.2
Pipe, valves & fittings	833.9	818.9	791.3
Process instruments	397.0	394.0	381.2
Pumps & compressors	973.5	966.0	965.0
Electrical equipment	512.1	510.7	507.7
Structural supports & misc	713.9	707.9	703.0
Construction labor	324.2	326.1	321.6
Buildings	547.0	546.0	536.6
Engineering & supervision	314.1	313.5	316.2

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

Annual Index:
- 2008 = 575.4
- 2009 = 521.9
- 2010 = 550.8
- 2011 = 585.7
- 2012 = 584.6
- 2013 = 567.3
- 2014 = 576.1
- 2015 = 556.8



CURRENT BUSINESS INDICATORS

	LATEST			PREVIOUS						YEAR AGO		
CPI output index (2012 = 100)	Jan. '17	=	101.9	Dec. '16	=	101.2	Nov. '16	=	101.3	Jan. '16	=	101.9
CPI value of output, $ billions	Dec. '16	=	1,860.7	Nov. '16	=	1,785.0	Oct. '16	=	1,780.7	Dec. '15	=	1,734.2
CPI operating rate, %	Jan. '17	=	74.8	Dec. '16	=	74.3	Nov. '16	=	74.4	Jan. '16	=	74.9
Producer prices, industrial chemicals (1982 = 100)	Jan. '17	=	241.9	Dec. '16	=	239.2	Nov. '16	=	239.8	Jan. '16	=	223.6
Industrial Production in Manufacturing (2012=100)*	Jan. '17	=	103.8	Dec. '16	=	103.5	Nov. '16	=	103.3	Jan. '16	=	103.4
Hourly earnings index, chemical & allied products (1992 = 100)	Jan. '17	=	168.1	Dec. '16	=	170.5	Nov. '16	=	169.5	Jan. '16	=	160.5
Productivity index, chemicals & allied products (1992 = 100)	Jan. '17	=	103.0	Dec. '16	=	102.6	Nov. '16	=	102.0	Jan. '16	=	103.0

CPI OUTPUT INDEX (2000 = 100)†

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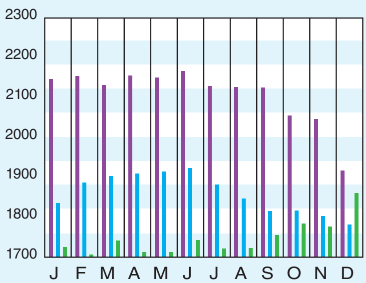

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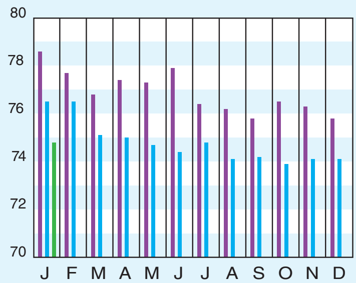

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†For the current month's CPI output index values, the base year was changed from 2000 to 2012
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CURRENT TRENDS

The preliminary value for the December *CE* Plant Cost Index (CEPCI; top; the most recent available) was higher than the previous month's value by a signficant margin for the second consecutive month. The jump was due to a rise in the Equipment subindex, along with increases in the Buildings and Engineering & Supervision subindices. The Construction Labor subindex saw a small decline. The preliminary December 2016 CEPCI value stands at 2.6% higher than the corresponding value from December 2015. This continues a months-long trend of higher year-over-year values. Meanwhile, the latest Current Business Indicators (CBI; middle) for January 2017 saw small increases in the CPI Output Index and the Productivity Index.


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