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Two-Part Feature Report on Process Safety
page 45

Facts at Your Fingertips: Gaskets

Rethinking Intellectual Property Policies

Better Filtration for the Bottom Line

Picking the Right Pressure Transmitter

page 34

Focus on Personal Protective Equipment

Pneumatic Conveying

Access Intelligence

CHEMICAL ENGINEERING 10 PRESSURE MEASUREMENT • PROCESS SAFETY VOL. 121 NO. 10 OCTOBER 2014


Manometer
150
10
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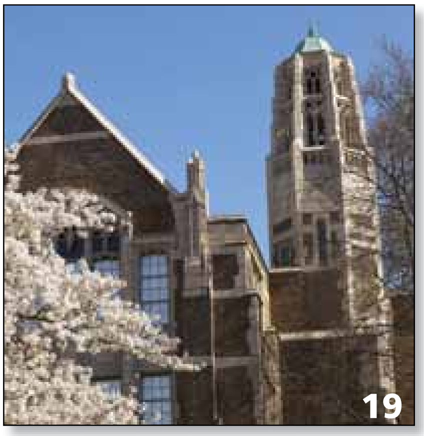

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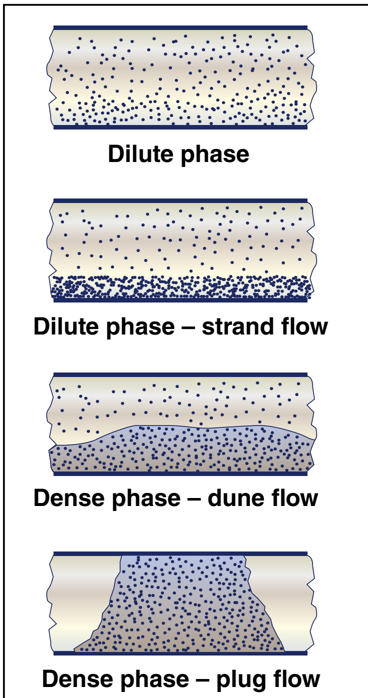

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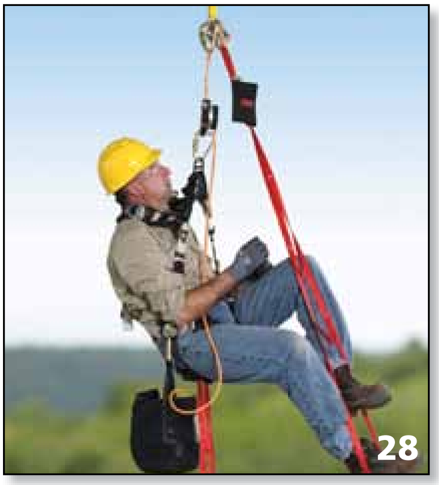

28

30

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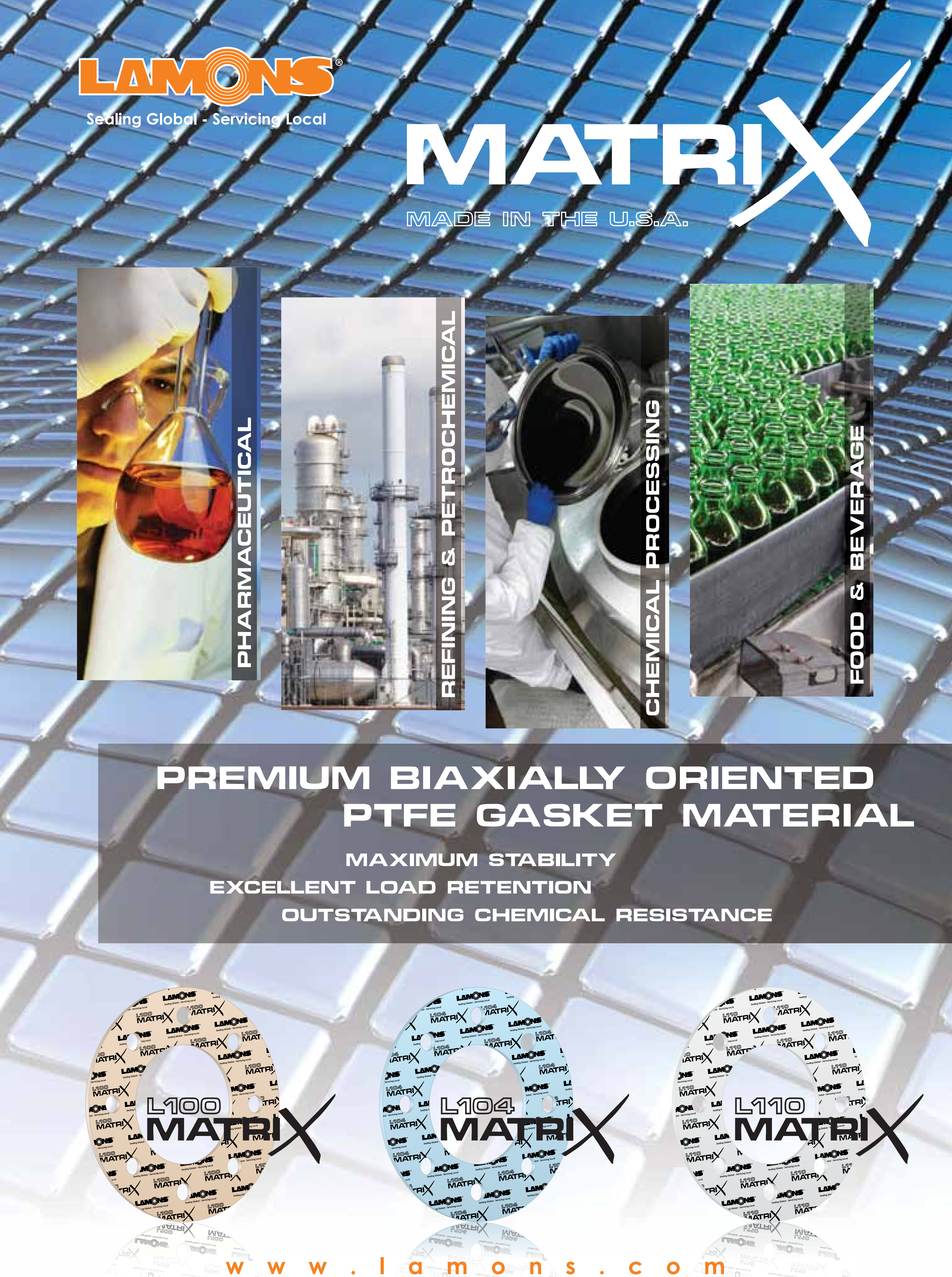

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CHEMICAL ENGINEERING

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Editor's Page

Focusing on STEM

I recently read an article in my local newspaper about the Museum of Math, also known as "MoMath" (New York; www.momath.org), which piqued my interest and prompted me to learn more about it. The gallery of photos and videos on the MoMath website reveal a fun, "hands-on" approach to learning mathematics. Many activities seem to be geared to children, but some of the offerings would appeal to any age bracket — I found myself engrossed in one of the "Math Encounters" videos on the website.

Innovative approaches to learning about science, technology, engineering and mathematics (STEM), such as MoMath, connect these disciplines to our everyday experiences and garner interest in further study. This is particularly of interest to industries, including the chemical process industries (CPI), that depend on a technically savvy workforce. Many have expressed concerns over the difficulty in finding highly skilled employees, and industries are helping to promote and fund STEM education to encourage interest.

In April of this year, for example, Siemens Corp., the U.S. subsidiary of Siemens AG (Munich, Germany; www.siemens.com) announced nearly $660 million of in-kind software grants to support educational manufacturing programs at institutions from high school through university levels in Massachusetts. The grants were established as a result of an industry need for skilled workers that was identified through the Massachusetts Manufacturing Extension Partnership (MassMEP; www.massmep.org) and the Manufacturing Advancement Center Workforce Innovation Collaborative (MACWIC; both Worcester, Mass.; www.macwic.org).

Also in April, Bayer Corp., the U.S. subsidiary of Bayer AG (Leverkusen, Germany; www.bayer.com) announced an investment of more than $400,000 to strengthen STEM education with grants and scholarships targeted at middle and high schools in the Houston area.

And in June, the Marbles Kids Museum (Raleigh, N.C.; www.marbleskidsmuseum.org) opened the "Kid Grid," a hands-on exhibit that introduces children to power-grid technology. The Kid Grid was funded by a $1-million grant from ABB (Zurich, Switzerland; www.abb.com) to inspire a new generation to study STEM.

The U.S. Government is also addressing the need to stimulate STEM learning. This summer, U.S. Senators Chris Coons and Lindsey Graham introduced bipartisan legislation to help engineering schools meet the growing demands of industry. "The Manufacturing Universities Act of 2014" would establish a program within the National Institute of Standards and Technology (NIST) to designate 25 universities as "manufacturing universities." The designated schools would receive funds to meet specific goals that focus on manufacturing needs of targeted industries. According to Senator Coons' press office, the legislation has received endorsements from a number of educational institutions, as well as from The Dow Chemical Company and DuPont.

There are many more programs focused on encouraging STEM education than there is room to list here. And in addition, there are more ways that industry and education are interacting — see, for example our Newsfront on Rethinking Intellectual Property Policies on p. 19 of this issue. Learning is a continuous process — I'm planning my visit to MoMath soon. ■

Dorothy Lozowski, Editor in Chief

Combustion control

It is good to see your magazine publishing articles highlighting the tangible benefits that process control is capable of bringing to the chemical process industries [Advanced Control Methods for Combustion, *Chem. Eng.* September, 2014, pp. 34–39].

While the authors seem to be up-to-date as far as new sensors in the combustion systems is concerned, they don't seem to be aware of several issues when it comes to control and advanced control. Even though all the processes are nonlinear, linear feedback is capable of successfully dealing with keeping the process variable close to the setpoint at all times (provided that the field devices are working properly).

MPC [model predictive control] is also a linear technology. MPC is not a match to the PID [proportional, integral derivative] controller, the model predictive role in process control is optimization of a process that needs to be steady-state stable to begin with. MPC is a technique that inherently optimizes setpoint tracking, and in consequence it has very poor performance when it comes to load disturbance rejection.

Sigifredo Nino, Process Control Consultant
Summa Control Solutions Inc., Montreal, Canada

We are very pleased about the professional reflection our paper has initiated!

Control theory is of course a rather diversified area, as it is reflected by the internal structure of the paper. Although this topic covers the majority of it, it was still not possible to touch a number of rather important issues, some of which the commenter missed. This is a good opportunity for clarifying some issues that seem to be the most important ones as follows:

Yes, it is an established fact that disturbance rejection capabilities of MPC do not belong to its strengths, it very often falls behind a PID controller. However, this is true only for unmeasured disturbances! One of the great strengths of MPC is its capability for excellent, model-based compensation of measured disturbances, regarding which it definitely outperforms many other control methods. And the second well-known weak point of MPC, which the commenter did not mention, is its higher sensitivity against model inaccuracies.

Yes, the basic MPC algorithm is a linear one, however, significant process nonlinearities can be handled by means of several nonlinear MPC versions, or some other approaches like "multimode control" or "gain scheduling" as mentioned later in the article.

Pál Szentannai
Budapest University of Technology and Economics
Maximilian Lackner
Vienna University of Technology

Editor's note: The above are excerpts of letters received on this topic. For the full text, and to take part in the discussion, search the article title, Advanced Control Methods for Combustion, on our website at www.chemengonline.com

Calendar

NORTH AMERICA

American Chemical Soc. — Midwest Regional Meeting. American Chemical Soc. (Washington, D.C.). Phone: 800-227-5558; Web: acs.org
Columbia, Mo. **November 12–15**

International Lubricants & Waxes Conference. AFPM (Washington, D.C.). Phone: 202-457-0480; Web: afpm.org
Houston **November 13–14**

International Water Conference. Engineers' Soc. of Western Pennsylvania (Pittsburgh, Pa.). Phone: 412-261-0710; Web: eswp.com/water/
Orlando, Fla. **November 15–19**

Practical HAZOP/PHA Team Leadership in Action. Chilworth U.S. (Princeton, N.J.). Phone: 609-799-4449; Web: chilworth.com
Princeton, N.J. **November 17–19**

Process Safety Management for Employee Safety, Reliable Operations and Business Advantage. Chilworth U.S. (Princeton, N.J.). Phone: 609-799-4449; Web: chilworth.com
Princeton, N.J. **December 3**

22nd Winter Fluorine Conference. American Chemical Soc., Div. of Fluorine Chemistry (Washington, D.C.). Phone: 800-227-5558; Web: acs.org
St. Pete Beach, Fla. **January 11–16, 2015**

5th Electric Energy Storage Conference. Marcus Evans North America (Chicago, Ill.). Phone: 312-894-6310; Web: marcusevans.com
San Diego, Calif. **January 13–15, 2015**

2nd Annual Combined Cycle Operations & Maintenance. Marcus Evans North America (Chicago). Phone: 312-894-6310; Web: marcusevans.com
Orlando, Fla. **January 21–23, 2015**

Informex 2015. Socma (New York, N.Y.). Phone: 609-865-6641; Web: informex.com
New Orleans, La. **February 3–5, 2015**

19th Annual Annual ARC Industry Forum. ARC Advisory Group (Dedham, Mass.). Phone: 781-471-1000; Web: arcweb.com
Orlando, Fla. **February 9–12, 2015**

EUROPE

Excellence in Shutdowns and Turnarounds in Oil and Gas. Marcus Evans Events (Chicago, Ill.). Phone: 312-894-6310; Web: marcusevans.com
Amsterdam, The Netherlands **November 20–21**

Calendar

Valve World Expo 2014. Messe Düsseldorf North America (Chicago, Ill.). Phone: 312-781-5180; Web: mdna.com
Düsseldorf, Germany **December 2–4**

10th Status Seminar for Chemical Biology. Dechema e.V. (Frankfurt am Main, Germany). Phone: +49-69-7564-277; Web: dechema.de
Frankfurt am Main **January 21–23, 2015**

14th International Electronics Recycling Congress IERC 2015. ICM AG (Birrwill, Switzerland). Phone: +41-62-785-1000; Web: icm.ch
Salzburg, Austria **January 21–23, 2015**

ASIA & ELSEWHERE

World Petrochemical (China) Summit 2014. Future Events (Shanghai, China); Phone: +86-21-6139-8055, Ext. 8047; Web: fevents.org
Shanghai, China **November 5–7**

Electronics Recycling Asia 2014. ICM AG (Birrwill, Switzerland); Phone: +41-62-785-1000; Web: icm.ch
Singapore **November 11–14**

Indometal 2014. Messe Düsseldorf (Chicago, Ill.). Phone: 312-781-5180; Web: mdna.com
Jakarta, Indonesia **December 11–13**

ArabPlast 2015. Messe Düsseldorf North America (Chicago, Ill.). Phone: 312-781-5180; Web: mdna.com
Moscow, Russia **January 27–30, 2015**

Interplastica. ICS Convention Design, Nanotech Committee (Tokyo, Japan). Phone: +81-3-3219-3567; Web: nanotechexpo.jp
Tokyo, Japan **January 28–30, 2015**

Nano Tech 2015. ICS Convention Design, Nanotech Committee (Tokyo, Japan). Phone: +81-3-3219-3567; Web: nanotechexpo.jp
Tokyo, Japan **January 28–30, 2015**

3W Expo 2015 (Water, Wastewater and Waste Treatment) and CPPE 2015 (Exhibition on Chemical & Process Engineering and Pollution Engineering). TechnoBiz Group (Bangkok, Thailand). Phone: +66-2-933-0077; Web: 3w-expo.com
Bangkok, Thailand **February 29–31, 2015**

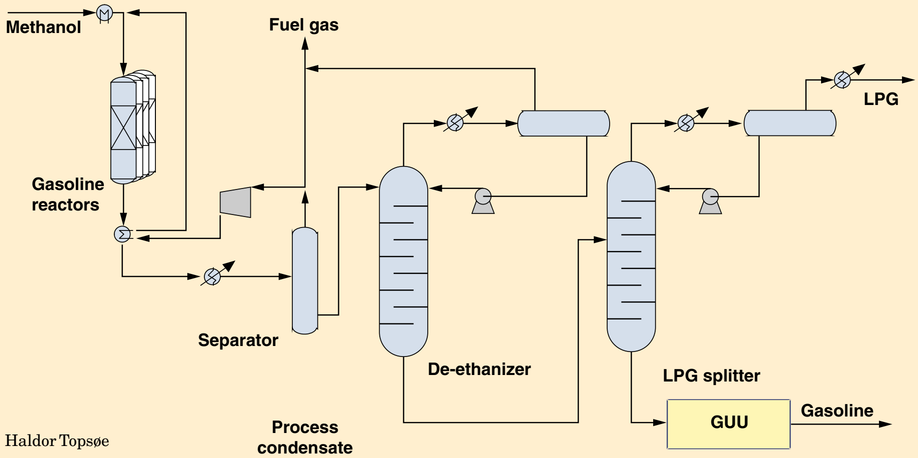
PlastIndia 2015. PlastIndia Foundation (Mumbai, India). Phone: +91-22-26832911-14; Web: plastindia.org
New Delhi, India **February 5–10, 2015**

GlasspexIndia. Messe Düsseldorf North America (Chicago, Ill.). Phone: 312-781-5180; Web: mdna.com
Mumbai, India **March 13–15, 2015** ■

Suzanne Shelley

The commercial debut for a gas-to-gasoline process

Last month in Ovadan-Depe, Turkmenistan, construction began on a plant that will produce gasoline from natural gas. When the plant starts up approximately four years from now, it will produce 15,500 barrels per day (bbl/d) of synthetic gasoline using the Topsøe Improved Gasoline Synthesis (Tigas) technology of Haldor Topsøe A/S (Lyngby, Denmark; www.topsoe.com). It will be the first large-scale project in the world utilizing the Tigas process.



Haldor Topsøe

Tigas is a process to make gasoline from synthesis gas (syngas, a mixture of CO and H_2) derived from natural gas, shale gas, associated gas, coal, petcoke or biomass, or from methanol or dimethylether (DME). In the Turkmenistan project, syngas will be produced by autothermal reforming of natural gas, and then converted into methanol using Topsøe technology, says Heinrik Udesen, business-development manager. The methanol will then be converted to gasoline via the Tigas process.

In Tigas (flowsheet), methanol is fed to parallel adiabatic gasoline reactors, which allow for intermittent catalyst regeneration (de-coking). In these packed-bed reactors, methanol is "polymerized" into hydrocarbons, using Topsøe's GSK-10 catalyst at a temperature of around 300–400°C and pressure below 20 bars. The catalyst — a type ZSM-5 zeolite — has a high selectivity for producing hydrocarbons in the range of C5 to C10, explains Udesen.

Gasoline production makes up more than 85% of the product stream, with liquefied petroleum gas (LPG) accounting for about 11–13% of the total product stream, says Udesen. The raw gasoline can be blended directly into the regular gasoline pool, or treated with a new gasoline upgrade unit (GUU) — comprised of an additional catalytic step to isomerize the heavy fraction gasoline into a high-octane fraction — to make high-value gasoline, with an octane number (RON) of 93, making it suitable as a "drop-in" fuel, says Udesen.

Combine wastewater treatment with biofuel production

Algae Systems LLC (Daphne, Ala.; www.algaesystems.com) has inaugurated a demonstration plant that integrates municipal wastewater treatment with the cultivation of biofuel-producing algae. Pretreated and disinfected municipal wastewater is passed to Algae Systems' offshore floating-bag photobioreactors (PBRs), which are located in a bay off of Daphne's coast. There, the oxygen, nitrogen and phosphorous from the wastewater, along with atmospheric CO_2, are mixed with and consumed by freshwater algae. This algae is then processed into what the company calls bio-crude, via hydrothermal liquefaction (HTL) — a high-temperature, high-pressure process that decomposes the biomass. The bio-crude can be converted to a variety of valuable end products. In laboratory trials, the company has shown that its algae-based bio-crude can be upgraded to diesel fuel. The company's proprietary HTL process eliminates an energy-intensive drying step, since a partially dewatered algae slurry, rather than moisture-free biomass can be fed to the process.

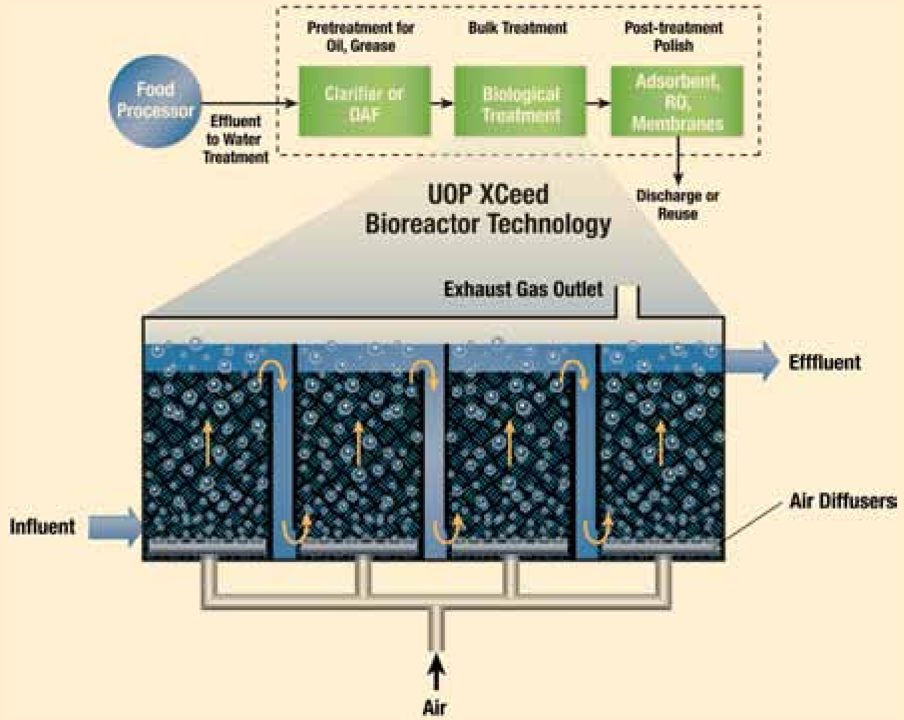
Algae Systems' PBRs provide a closed system where algae can flourish at a moderate ambient temperature. The bags rise and sink with the tide and the waves provide mixing. The algae that grows within the PBRs is a native, non-invasive freshwater species, so in the event of a release, it will not disrupt the bay's ecosystem.

The demonstration plant's PBRs presently reside on one-half acre of bay, but the company is planning to double that area in the coming months. The current wastewater-treatment capacity of the site is up to 40,000 gal/d.

Wavelength conversion

Last month, Hitachi Chemical Co. (Tokyo, Japan; www.hitachi-chem.co.jp) began marketing so-called wavelength-conversion particles for use in solar-encapsulant sheets, which boost the conversion efficiency of solar cells. These particles consist of phosphors contained within acrylic resin particles, and function by converting ultraviolet (UV) light, which could not previously be used for power generation, into longer-wavelength (visible) light. Solar cell modules that use wavelenth-conversion sheets made of these particles are expected to increase conversion efficiency by up to around 2.2%, says the company.

Hitachi says it has developed a mass-production system for manufacturing the new materials for sale. In addition to applications in solar cells, the technology can add new functionality to counterfeiting protection, identification of authenticity, optical materials and other applications through the use of wavelength conversion.



An energy-saving bioreactor for wastewater treatment

A bioreactor technology for removing organic and inorganic contaminants from industrial wastewater has been commercially launched by developer Honeywell and its subsidiary UOP LLC (Des Plaines, Ill.; www.uop.com). The launch is part of a wider initiative by UOP to respond to customer needs as it enters the industrial wastewater-treatment business.

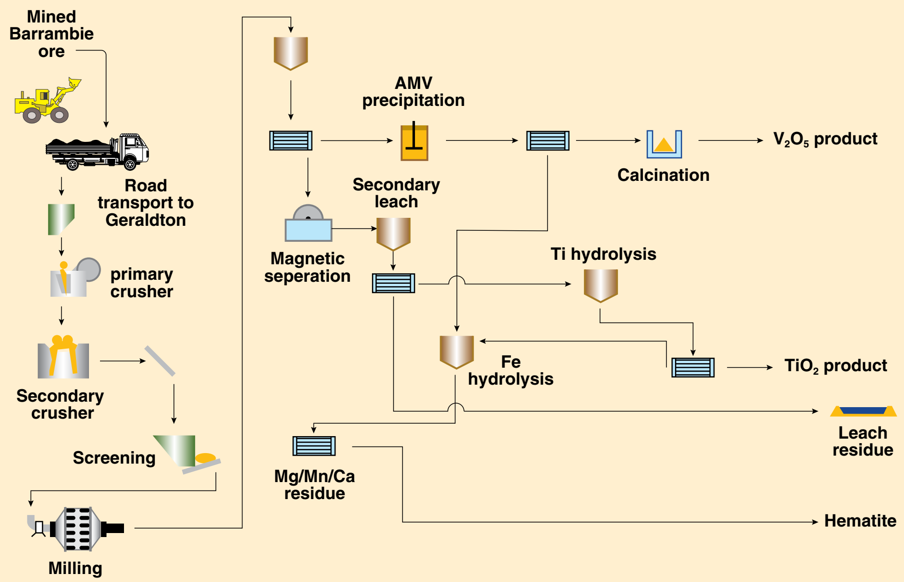
The XCeed bioreactor (diagram)is unique in its use of a mixed-media support for immobilized microbes. In contrast to alternative biological wastewater-treatment systems, including membrane bioreactors that use stirred-tanks to distribute the microbes, XCeed employs a fixed cell media that is populated by microbes. Influent wastewater flows through the immobilized cells, where contaminants are removed.

"The fixed bed of immobilized microbes allows us to create higher microbial densities and more sophisticated microbial communities," says Alan Greenberg, UOP senior water business manager. "And since the bugs are fixed, there is no need for mechanical stirring, which reduces energy usage by up to 60%" compared to alternative biological wastewater treatment systems, adds Abigail Antolovich, strategic marketing manager for UOP's water-treatment business. The immobilized-cell approach was originally conceived in the 1990s, and is now being leveraged in UOP's wastewater business.

With the ability to support a more diverse microbial ecosystem within the fixed media, XCeed allows for biomass retention times that can exceed 100 days, compared to typical retention times of 10–21 days in other biological treatment systems, Greenberg says. Longer retention time leads to reductions of up to 80% in sludge produced, which lowers disposal costs.

While the XCeed system is available as a pre-fabricated, skid-mounted assembly with a relatively small footprint, each system is customized according to the contaminant profile of the water, Antolovich notes. XCeed has been used to treat contaminated groundwater and wastewater from several industries.

A step forward for a new titanium leaching process



Reed Resources Ltd. (Perth, Western Australia; www.reedresources.com) has advanced its Barrambie Titanium Project — about 600 km northeast of Perth, Western Australia — with the construction (now in its final stages) of a mini-pilot plant in Canada to demonstrate a transition from laboratory-scale batch testing to continuous operation.

Barrambie is one of the world's highest-grade titanium deposits, containing total indicated and inferred mineral resources of 47.2 million metric tons (m.t.) at 22.2% TiO_2, 0.63% V_2O_5 and 46.7% Fe_2O_3, at a cut-off grade of 15% TiO_2.

The plant will test a proprietary chloride-based process (flowsheet), pioneered in Canada, for the recovery of TiO_2, V_2O_5 and Fe_2O_3 from run-of-mine ore at a feedrate of 10 kg/d. It will test the operation of each of the major unit operations of the flowsheet on a continuous basis: leaching of the mineralized material, TiO_2 precipitation, iron hydrolysis, and acid regeneration.

(*Continues on p. 14*)

TITANIUM LEACHING *(Continued from p. 11)*

The company says a key feature of its patented process is the acid recovery and regeneration process, which shows the potential to operate at significantly lower costs than established technologies previously evaluated by Reed.

Reed will now start a pre-feasibility study of a hard-rock titanium mining and processing operation, to be completed in the first quarter of 2015. The study estimated average net operating costs of TiO_2 recovered at $1,214/m.t. with an indicative accuracy of ±35%, potentially placing the project at the low end of the global cost curve.

It is expected that run-of-mine ore will be crushed and screened at the mine site and then trucked to a processing facility near Geraldton, Western Ausralia, with a nominal capacity of 200,000 m.t./yr of feed, where high-purity titanium, vanadium and iron compounds will be produced.

This solar cell promises to be less expensive

A commercial prototype perovskite solar cell that is less expensive than current thin-film solar cells is under development by a team from Nanyang Technological University (Singapore; www.ntu.edu.sg), in collaboration with Dyesol Ltd. (Queanbeyan, NSW, Australia; www.dyesol.com) and professor Michael Grätzel from the Swiss Federal Institute of Technology (Lausanne; www.epfl.ch).

The team has produced solar cells made from perovskite materials using a simple solution-based manufacturing process. It studied organic-inorganic halide perovskite materials, such as $CH_3NH_3PbI_3$, as light harvesters in solid-state sensitized solar cells. Perovskite can convert up to 15% of sunlight to electricity, close to the 20% efficiency of commercial thin-

(Continues on p. 16)

New HTS catalyst

Last month, Clariant (Muttenz, Switzerland; www.clariant.com) introduced ShiftMax 120 HCF, an enhanced high-temperature shift (HTS) catalyst that contains essentially no (less than 200 parts per million) hexavalent chromium (Cr^{+6}). That means the catalyst avoids health and safety risks during handling and commissioning at hydrogen and ammonia-production plants. The low Cr^{+6} was independently confirmed by Seibersdorf Laboratories (according to OECD test No. 29). ShiftMax 120 HCF is thus fully compliant with REACH Regulations of the European Community (Annex XIV to EC No 1907/2006), which will inhibit the sale of compounds containing Cr^{+6} beyond a very low threshold.

The new ShiftMax 120 HCF is practically identical to its predecessor (ShiftMax 120) after initial activation, says the company. ShiftMax 120 HCF has already been successfully installed in several H_2 plants.

SOLAR CELL (*Continued from p. 14*)

film solar cells.

Until now, scientists did not understand the process by which those perovskite materials convert sunlight to electricity. The team achieved a detailed understanding of that process using femtosecond transient optical spectroscopy on bilayers that interface the perovskite with either selective-electron or selective-hole extraction materials. It discovered that in those materials the electrons generated by sunlight can travel lengths of at least 100 nm. This will allow making thicker solar cells that absorb more light and that generate more electricity. The properties of these materials will allow making lightweight, flexible solar cells on plastic using inexpensive processes, without sacrificing the good sunlight conversion efficiency. Another benefit of these materials is their ability to exhibit different translucent colors, such as red, yellow or brown, creating new opportunities for architectural design (that is, for incorporating solar cells into building roofs and facades).

Using algae to produce medium-chain-length fatty acids

Scientists at Kao Corp. (KAO; Tokyo, Japan; chemical.kao.com) have discovered an enzyme that has the potential for producing large quantities of medium-chain (C12) fatty acids (FAs), which are the main components of natural oils, such as palm-kernel and coconut-palm oils. Such FAs are precursors to surfactants used in shampoos and detergents. The discovery could lead to an alternative route to such FAs, without competing with natural, edible oils.

Since 2011, the company has been working on alternative sources for FAs at its Eco-Technology Research Center (ETRC). The researchers surveyed the composition of FAs produced from more than 1,200 algae strains, and identified several types that can accumulate the C12 fatty acid, lauric acid, up to 10 wt.% or more. The algae *Symbiodium sp.*, for example, has a high production capacity for FAs. It was shown that the amount of desired FAs can be increased by optimizing the environmental and cultivation conditions, such as the carbon source (glycerin) and nutrients (nitrogen and phosphorus). They also identified, for the first time, the enzyme acyl ATP thioesterase (TE), which determines the chain length of FAs produced.

KAO has shown that the C12 FAs produced by the algae are suitable for products, such as cosmetics and supplements, animal feedstuffs and biofuels. Further work is now being done to optimize the strain selection and to develop an extraction process for the commercial application of algae-based FAs, which the company says will be established by 2020.

A direct route to organosilicon compounds

Researchers from the National Institute of Advanced Industrial Science and Technology (AIST; Tsukuba City, Japan; www.aist.go.jp), with support from New Energy and Industry Technology Development Org. (NEDO; Kawasaki City; Japan; www.nedo.go.jp) have developed a technology to efficiently synthesize tetra-alkoxy-silane — a promising raw material for organosilicon compounds, such as silicone. Such materials are used in automobiles and solar cells. Unlike alternative routes, which either use a metallic-silicon intermediate, or an expensive dialkyl carbonate, the new synthesis process uses inexpensive raw materials (silica and alcohol). High temperatures are also avoided, making the new process a low-cost, energy-saving alternative to traditional methods, says AIST.

AIST's reaction process uses an organic dehydrating agent, which enables a direct, one-step synthesis of alkoxy-silane from silica and an alcohol. Removing the water byproduct during the reaction suppresses the reverse reaction. For example, an 18% yield is achieved after 24 h in the reaction of silica (99.7+%, 75–150-µm dia. particles) and methanol at 242°C using acetone dimethyl acetal as the dehydrating agent. Without the agent, a yield of less than 0.1% is observed. An even higher yield of 48% is achieved after 24 h (88% yield after 48 h) when introducing tetra-methoxy titanium and KOH under a CO_2 atmosphere of 2 MPa.

The researchers speculate that CO_2 activates the methanol to efficiently react with silica, while the tetra-methoxy titanium accelerates the reaction of methanol and CO_2, and the KOH promotes the decomposition of silica by cleaving the Si–O bond.

The researchers believe the dehydrating agent can be easily regenerated and reused. CO_2 is not consumed in the reaction and can also be reused. Furthermore, the new process is chlorine-free, thus avoiding the inevitable chlorine-contamination that occurs when using $SiCl_4$ as a raw material. The group is now working to enhance the efficiency further, optimize the recycling methods and scale up the process.

Bio-propane

A team of scientists from Imperial College London (www.imperial.ac.uk) and the University of Turku (Turun Yliopisto, Finland; www.utu.fi) has engineered *Escherichia coli* bacteria to produce propane. Using *E. coli* as a host organism, the scientists interrupted the biological process that turns fatty acids (FAs) into cell membranes. To interrupt the process, the researchers discovered a new variant of an enzyme called thioesterase that specifically targets FAs and releases them from the natural process. They then used a second bacterial enzyme, called CAR, to convert butyric acid into butyraldehyde. Finally, a hydrocarbon-generating enzyme, called aldehyde-deformylating oxygenase (ADO), converts the aldehyde into propane. The proof-of-concept study is a first step toward renewable propane. A commercially viable process may take 5–10 years of further development.

A step closer to bio-based acrylic acid

Last month, BASF SE (Ludwigshafen, Germany; www.basf.com), Cargill (Minneapolis, Minn.; www.cargill.com) and Novozymes (Copenhagen, Denmark; www.novozymes.com) achieved another milestone in the joint development of technologies to produce acrylic acid from renewable resources. The research team demonstrated the conversion of 3-hydroxypropionic acid (3-HP) to glacial (water-free) acrylic acid and superabsorbent polymers.

The three companies began the quest for a process to convert renewable raw materials into acrylic acid in August 2012. The first milestone was reached in July 2013 with the demonstration of the production of 3-HP — one potential precursor for acrylic acid — at pilot scale.

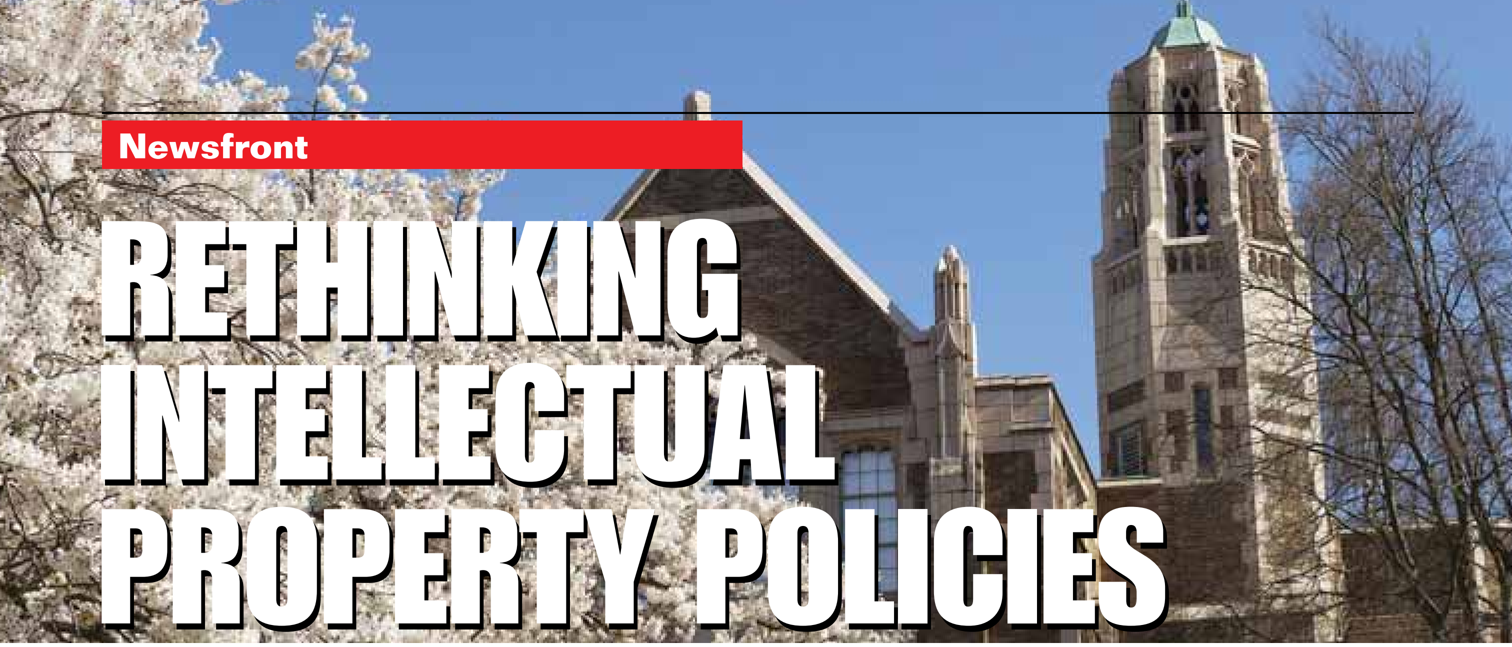
BASF initially plans to use bio-based acrylic acid to make superabsorbent polymers, which are used in diapers and other hygiene products. Currently, acrylic acid is produced by the oxidation of propylene, which is derived mainly from petroleum. Now, just 18 months after the collaboration began, BASF has selected the preferred process to convert 3-HP into glacial acrylic acid. A small integrated pilot plant is being set up, and could be operating by the end of this year. Together with the pilot plant for 3-HP, operated by Cargill with support from Novozymes, BASF plans for a fast market entry of superabsorbent polymers derived from bio-based acrylic acid. ■

A 'greener' cement

Researchers from the École Polytechnique Fédérale de Lausanne (EPFL; Switzerland; www.epfl.ch), together with partners from three Indian Institutes of Technology, and universities in Cuba and Brazil, have managed to double the quantity of cement produced from the same quantity of limestone by substituting a large portion of clinker (an intermediary material made by heating limestone at very high temperatures) with calcined clay. Limestone Calcined Clay Cement (LC3) has the potential to generate 20–30% less CO_2 emissions compared to traditional Portland cement; a major reduction considering that cement accounts for 5–8% of today's manmade emissions.

Although slag and flyash are already used worldwide to decrease the ratio of clinker needed to manufacture cement, these materials are not always available locally and their limited supply will not be able to meet the rapidly increasing demand for cement. LC3 can use low-grade kaolin clays, which are unsuitable for most industries and largely available in many parts of the world, including India. LC3 is a low-carbon and low-cost cement that delivers similar or even superior performance properties compared to Portland cement. The blend can be easily manufactured in existing production lines, requiring only minor capital investments.

India is the first country where LC3 is being tested, both in the laboratory and in the field (on a large scale). ❑



RETHINKING INTELLECTUAL PROPERTY POLICIES

Shifts in university policies surrounding IP in industry-funded research mean expanded opportunities for CPI companies

A philosophical shift in the way universities treat intellectual property (IP) resulting from industry-sponsored research could mean substantial benefits to companies in the chemical process industries (CPI). Specifically, large research universities in the U.S. are adopting, developing or considering policies designed to streamline the process of establishing research agreements and to transfer ownership of the IP resulting from industry-funded research to the sponsor.

Industry-funded research often involves complicated research contracts and protracted negotiations over the terms related to IP that result from the research. Universities and companies alike have long been frustrated by the often time- and labor-intensive process.

Now that is changing. The more flexible attitude toward IP and the simplification of research agreements are likely to increase the number of industry-university partnerships and offer significant new opportunities for companies that may not have considered academic partnerships before. At least two examples of universities that have already adopted re-modeled IP policy are demonstrating positive results.

"The adoption rate [for flexible IP policy] is undoubtedly on the rise" among U.S. universities, agrees Jay Schrankler, director of the Office for Technology Commercialization at the University of Minnesota (Minneapolis; www.umn.edu).

Companies are taking notice. "At Dow, we absolutely anticipate benefits from the changes in the U.S. in how IP is handled [in university-industry partnerships]," says Gretchen Baier, associate R&D director for external technology at The Dow Chemical Co. (Midland, Mich.; www.dow.com). Overall, it appears that the situation with IP ownership is improving, Baier says, and that a "critical mass" of universities is starting to re-evaluate their policies in this area.

Factors driving change

Several factors have combined to create an environment for the development and adoption of new IP approaches. Among them is a growing realization on the part of universities that strict control over the IP coming out of academic research has not generated the revenue that was envisioned when the original IP policies were set up 30 years ago following the passage of the Bayh-Dole Act (see sidebar, p. 20). The law transferred the IP rights of federally funded academic research to the universities, which then set up offices to manage the IP. The Bayh-Dole Act does not apply to research supported by companies, but most universities have applied the same practices of retaining IP ownership in company-sponsored research anyway, hoping to derive revenue from licensing the technology to companies for commercialization. Except for a handful of exceptional cases, mostly in pharmaceutical research, substantial revenue has not materialized. Universities report that revenue from industry-sponsored research has been lower — sometimes significantly — than the expenditures for protecting IP and establishing licensing agreements.

Low licensing revenues, coupled with a renewed focus on how best to drive the transfer of technology from the laboratory to commercial use, has sharpened the push for reform in industry-supported research.

"Every school has a unique culture and different core values, so there is not a universal approach to IP management that will work for all universities," remarks Tony Boccanfuso, executive director of the University-Industry Development Partnership (UIDP), an initiative of the National Academies (Washington, D.C.; www.nationalacademies.org), "but it is in the interest of all universities to evaluate how they handle external agreements [with industry], spinoffs and licensing of IP."

The UIDP, which counts several major chemical companies among its 125 members, aims to improve collaboration between universities and companies by trying new approaches to working together, explains Boccanfuso. UIDP recently

THE RISE OF UNIVERSITY IP

For most of the post-WWII period, the ownership of intellectual property (IP) from federally funded research at universities resided with the government agencies that funded the work. That changed in 1980 with the passage of the Bayh-Dole Act, which transferred IP rights from the funding agency to the university in an effort to push the products of federally funded research into the commercial marketplace. Following the advent of Bayh-Dole, universities formed IP offices to help seek patents for university-developed technology and to arrange licenses for commercialization of the technology. The thinking was that technology licensing could generate revenue for the university while still achieving the law's goal of more widespread commercialization of research products.

Although the Bayh-Dole Act applies only to federally funded research, universities generally applied the standard to all research, and have insisted upon maintaining ownership of intellectual property derived from industry-funded research as well. The conventional wisdom followed by many research universities suggested that the IP developed during industry-funded research would hold higher potential value because it is applied research.

Data compiled at Penn State University (PSU) indicated that the expenditures for creating and managing IP were outpacing revenues generated through licensing by a significant margin over extended time periods. The situation is similar at most other leading research universities — very few have generated outstanding IP revenue.

In a paper published in 2012 in the journal *Research-Technology Management*, former PSU administrator Hank Foley concluded that the university's insistence on owning IP derived from industry-funded research "is not beneficial to the institution, to our students and to the public that the university was established to serve." In the article, Foley outlined PSU's intention to establish more flexible IP policies and to use research agreements that "provide real value to the industry partner and to the university by building end-to-end partnerships." ❑

led an effort investigating ways that universities could facilitate company access to foreground IP rights from industry-sponsored research projects (see sidebar, p. 21).

The vanguard

The Univ. of Minnesota and Penn State Univ. (PSU; State College; www.psu.edu) are the two schools that have led the way in changing the way that IP is handled in industry-funded academic research. Both schools launched programs in 2012 that are now being evaluated, and in some cases emulated, as other universities consider how best to adapt.

In a departure from conventional practice, PSU gives companies that fund research at the university the option of requesting ownership of the IP resulting from the sponsored project. The more flexible IP policy, begun in July 2012, was part of a wider effort to improve interactions with industry that was outlined in a 2012 article by Hank Foley, then PSU vice president for research.

"The university is happy with [the new policy] overall, and the companies like it as well," reports Ron Huss, director of the technology transfer office at PSU. "It has improved the relationship between faculty and the technology transfer office, because it has been a faster, smoother administrative process of funding and licensing," he adds.

PSU changed its policy for several reasons, but Huss says the main one was "to reduce the time, effort and energy required to put a sponsored research agreement in place, including attorneys time and resources."

"We want the policy to help break down barriers to industry-sponsored research," adds Don Mothersbaugh, senior technical specialist in PSU's Office of Technology Management.

While company sponsors can easily own IP from research they sponsor at PSU, the university maintains the right to use the IP for research and education purposes. PSU has also established a "bonanza clause," which asks the sponsor to share revenue proportionally in the case of "exceptional commercial success."

PSU handles $40 million annually in industry-funded research (this total excludes subcontracts and federal flow-through dollars), and there have been hundreds of individual projects since the university enacted the policy shift in July 2012. "The researchers are happy because less time is required to negotiate research contracts," Huss says. "There is a standard research agreement [to allow sponsors to own the IP], and about one-fifth of the time, the sponsor agrees to sign outright. Other times, small modifications are made," Huss says.

Around the same time PSU was laying out changes to its IP ownership policy, the University of Minnesota was launching a program called Minnesota Innovation Partnerships (MN-IP), in which a company sponsoring research at the university can pre-pay a premium on funding dollars and receive an exclusive worldwide license for any technology developed from the project.

The motivation for starting the program came from industry "customers" saying that it was becoming too difficult to work with the university, says Minnesota's Schrankler.

Schrankler continues, "the MN-IP program is trying to avoid the situation where a company comes to the university, and pays for research and then has to negotiate for the rights to an invention that comes out of it." The key aspect of the program is that by increasing upfront funding by 10%, the company gets exclusive licensing rights to the IP, and does not have to pay any royalties until over $20 million in sales. And even then, it's only a 1% royalty rate, Schrankler explains. If the IP leads to improvements to already existing processes or products, the royalty payments are capped at $5 million, Schrankler says.

Minnesota later added the "Try and Buy" component to the MN-IP program, which allows companies to "test-drive" university technology before purchasing usage rights, Minnesota says. "Companies can try the technology first before they decide to license it," Schrankler says, adding, "and now royalty rates are published — universities traditionally have not published those."

The feedback from industry has been extremely positive, and the numbers of industry research sponsors has increased significantly in the two years since we introduced the program, Schrankler reports. We have well over 100 research agreements with 75 new companies, he says. However, the spending level per project has not expanded. "One very important outcome is that we have gotten many more companies into the game," Schrankler says.

In what represents a "feeling out" process on the part of companies, the use of the program has not been uni-

KEY ATTRIBUTES OF NEW MODELS

The following is a list of practices, outlined by the UIDP, that universities are considering or in some cases, have incorporated as components of new university approaches to handling industry-sponsored research.

Increased availability of BIP. Making university-owned background intellectual property (BIP; referring to IP generated prior to the start of the collaboration) available for licensing. BIP may be considered for separate licensing or be licensed as a part of a sponsored-research agreement in a similar manner as foreground intellectual property (FIP; referring to IP generated during the collaboration).

University use of industry-owned BIP. Universities may allow sponsored research involving industry BIP. Industry retains the exclusive rights to BIP and any resultant modifications in most of these agreements.

Sponsor FIP ownership. Assignment of university-owned FIP to the sponsor.

Post-development license terms. Allowing the possibility of post-development license terms. Licensing terms are negotiated only if the IP is developed under the agreement and the sponsor plans to commercialize the IP. This is often paired with a royalty-bearing license.

Upfront paid FIP license. This license is often charged as the percentage of the sponsorship agreement (10–15%) or as a standard fee

FIP royalties. Payment of royalties on resultant product sales

"Bonanza clause". Royalties to be paid above a large sales threshold ❏

versal, however. Interestingly, only one-third of industry funders elect to pay the higher upfront cost to guarantee the rights so far. The majority elect to still stick with the "old-fashioned way," says Schrankler. Despite that, the perception of the university in the business community has improved, and the extra upfront payments have helped the university in its education mission.

The MN-IP program has been utilized in a wide range of academic departments, with an emphasis in engineering fields, Schrankler says.

The second wave

Even as the PSU and Minnesota IP programs continue to be evaluated — the jury is still out on what works best and what the overall effects on the research enterprise are — a second wave of universities is now moving to change their own IP policies.

According to Schrankler, several universities have modeled practices after the first two, including Iowa State (Ames; www.iastate.edu), Univ. of Arizona (Tucson; www.arizona.edu), North Carolina State Univ. (Raleigh; www.ncsu.edu) and Georgia Tech (Atlanta; www.gatech.edu). Purdue Univ. (West Lafayette, Ind.; www.purdue.edu), Univ. of Oregon (Eugene; www.uoregon.edu) and Univ. of Michigan (Ann Arbor; www.umich.edu) are others that are also now moving to change. Additional schools, such as the state university systems of California and Texas, have inquired about the Minnesota program, Schrankler says, and are likely to enact their own changes in the future.

What industry wants

Evidence exists that the changing IP policies align well with what industry is looking for in funding research at universities. William Banholzer, Univ. of Wisconsin (Madison; www.wisc.edu) chemical engineering professor and former CTO at Dow, says university research groups are great places to seek expertise, but universities should strive to remove roadblocks to working with industry. "It has to be easy," he remarks.

Dow will not collaborate with universities when the total monetary exposure, including royalties, is not defined up front, says Dow's Baier. "Transferring IP ownership to the sponsor makes the whole situation more efficient on all sides," she says.

BASF SE (Ludwigshafen, Germany; www.basf.com) states that "option periods and payment conditions should take into account that there is a long timeline from invention in a laboratory to the marketplace. Short option periods and excessive financial demands in this phase create serious obstacles for the industry partner."

Industry wants to avoid situations where a company funds research to help solve a problem, and subsequently cannot agree on licensing terms with the university on IP developed. This could result in the technology being licensed to a competitor, Baier points out. "One can imagine that a competitor would be willing to pay more to license, since they didn't fund the research to begin with, plus they could then block [their competitor]," Baier says.

"By having terms defined upfront, we feel comfortable sponsoring more projects at universities; plus, the projects are more relevant to us and more collaborative in execution. This is really a win-win situation," Baier remarks.

Clear path forward

From the vantage point of both companies and universities, new approaches to industry-sponsored research paints a positive picture for future interactions between the two.

"In the future, with [U.S.] federal funding for academic research largely flat or declining, there will be more industry-university involvement and more integrated activity between the two groups," says Minnesota's Schrankler.

Enhanced university-industry interaction will have wide-ranging positive effects beyond the way IP is handled, including in general economic and workforce development. As it provides new opportunities for companies, it will help universities to be better economic drivers. ■

Scott Jenkins

Editor's note: For a longer version of this article, visit www.chemengonline.com.

BETTER FILTRATION FOR THE BOTTOM LINE

Advanced filtration methods reduce costs and increase productivity

Camfil APC

FIGURE 1. The Farr Gold Series Camtain dust collector offers bag-in/bag-out filter change out to help keep employees safe during handling of potent dusts

Many applications in the chemical process industries (CPI) require filtration — from cleaning the air of dust, to corrosion prevention, to cleaning up incoming process water, to recovering proteins downstream. No matter the application, filtration providers are working to improve technology for their chemical processing customers because better filtration leads to a higher-quality product, less maintenance and downtime and other benefits that result in a better bottom line.

Here, experts in all segments of the filtration industry weigh in on the latest advances in their respective technologies and how these improvements can help users in the CPI.

Clearing the air

While there are many aspects of air filtration required in the CPI, dust collection is a major focus for processors. "Keeping the air and the employees in their facilities safe are pressing issues for our chemical processing and pharmaceutical customers," says Rick Kreczmer, aftermarket sales manager, with Camfil APC (Jonesboro, Ark.; www.farrapc.com).

For this reason, Camfil APC was concerned with how the dust that comes into the dust collection unit is handled, especially regarding the filters that collect the dust and the discharge area where the dust comes out. "Too often, a maintenance technician had to interface with the dust collector to change the filter, which is likely coated with dust from a potent drug or chemical in these particular industries. Something needed to be done to make this safer for the personnel," he says. "Further, a lot of dust goes into a collector and comes out at a discharge point. Again, we needed a safer method of handling this dust in these applications."

In response, Camfil devised the Farr Gold Series Camtain dust collection system (Figure 1), which includes safe-change containment systems for the filter cartridges and discharge area. The cartridge change uses a bag-in/bag-out (BIBO) method that employs cam-lock action so personnel do not come in contact with the filters, while the discharge uses continuous liner technology and a crimp-and-clamp process so maintenance technicians can remove the bag without exposing themselves to the chemicals.

Kreczmer says the dust collector has been tested by an independent company and results show that the occupational exposure level of the Camtain collector is less than 0.4 $\mu g/m^3$. "These results ensure the safety of the operators because they don't run the risk of coming in contact with potent drugs or chemicals," he says.

In a related issue, any time a processor is dealing with toxic dust, exposure limits are obviously a concern, continues Kreczmer. For this reason, industry professionals have been working to improve the efficiency of nanofiltration technologies, and in the past few years, the MERV (minimum efficiency reporting value) ratings on these filters have improved dramatically. Camfil offers the HemiPleat eXtreme media, which provides a MERV 15 efficiency rating, higher than that of the base-paper rating of MERV 10 and higher than other nano web products, which typically offer a MERV 13 rating.

The better efficiency, he says, is due to the tri-layered technology (Figure 2), which allows the use of standard base material and adds two additional layers without compromising the pressure drop. It also allows the base material to have larger pore sizes than standard cellulose products, reducing pressure drop and improving filtration efficiencies. HemiPleat eXtreme can withstand rigorous pulse-cleaning, which extends filter life and lowers operating costs. "This technology allows users to keep the filters in the dust collector longer, which saves

Camfil APC

FIGURE 2. **Shown here is the base media with a nano fiber coating as found in the HemiPleat eXtreme nano fiber filters, which offer high efficiencies**

Purafil

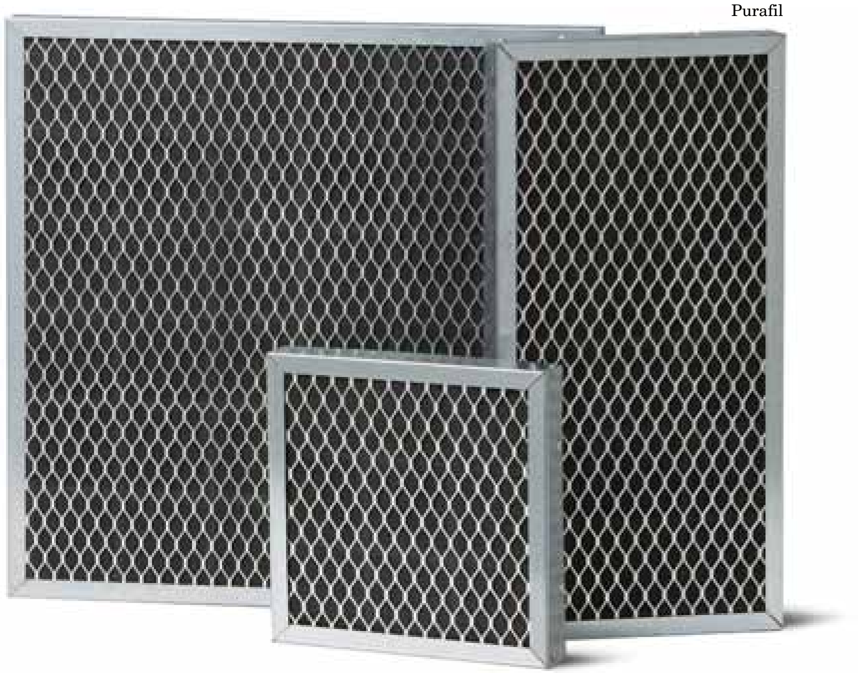


FIGURE 3. **PuraGRID uses extruded carbon composites incorporated into the GridBLOK delivery system**

the cost of the filters and reduces the maintenance and disposal costs associated with more frequent changeovers," notes Kreczmer.

Not only can the environment in a chemical facility be toxic to the employees, it isn't particularly easy on the equipment either, notes Chris Muller, technical director with Purafil (Doraville, Ga.; www.purafil.com). Protecting critical equipment in control rooms became even more of an issue following the rollout of the 2006 Restriction of Hazardous Substances directive (RoHS), which necessitated a switch to lead-free manufacturing of electronic products. "Some of the more common materials used as replacements were more sensitive to common atmospheric pollutants than the lead-based materials were," Muller explains. "Due to high rates of failure, processors needed to add filtration in areas where they never needed it before, or use a different type of system to control corrosion of the silver [which replaced the lead] on circuit boards and devices."

Last year, the International Society of Automation (ISA; Research Triangle Park, N.C.; www.isa.org) released a new standard (71.04-2013) to help the IT industry specify acceptable air quality in mission-critical environments, such as control rooms. Processors now have an air-quality goal that, if met, helps ensure that equipment will be essentially free from corrosion-related failures.

However, a significant challenge still remained, says Muller. "A lot of facilities had difficulty fitting an air-cleaning system into their control rooms, because some of the systems required for this level of corrosion protection and air cleaning can be large — 8 ft by 8 ft or 10 ft by 15 ft," he says. "So we began to look for ways in which we could incorporate chemical filtration into existing systems and smaller areas."

What Purafil came up with is called PuraGRID (Figure 3), a new filter that is designed to supply a

large amount of chemical filtration with minimal amount of pressure drop in a smaller footprint. Historically, filters for these applications used various sized and shaped pellets, but PuraGRID uses extruded carbon composites incorporated into the GridBLOK delivery system.

GridBLOK is a gas-phase air-filtration medium in the form of an extruded monolithic block consisting of a large number of small parallel cells or channels. GridBLOK is composed of 100% adsorbent materials, allowing the entire composite structure to function as a gas filter. Due to the large number of cells in each unit, the contact area between the adsorbent layer and the airstream that travels inside the cells is very large. Further, the cells are parallel so that the flow is not obstructed and the pressure drop across the GridBLOK is very low. The cellular geometry of the extruded GridBLOK provides a high surface area per unit volume, allowing it to provide more filtration in a smaller area, according to Muller. "This is a way to put more filtration into areas where it couldn't go before due to limitations on space or energy consumption [less energy is needed to blow air through the new filter] or restrictions due to budgets that did not permit installation of a new air-cleaning system."

Lakos Separation and Filtration Solutions

FIGURE 4: The JPX Series liquid-solids separation system offers maximum protection for fluid handling systems from unwanted solids

In response to similar issues, experts at Universal Air Filter (UAF; Sauget, Ill.; www.uaf.com) wanted to develop an advanced protective, high-efficiency, chemical-resistant air filter medium that could resist moisture and microbial growth in industrial electronic enclosures.

3M Purification

FIGURE 5: 3M Emphase AEX Hybrid Purifier employs a combination of two types of media that work together to provide product purity after clarification when using a single-unit operation

Dan Krupp, director of sales and engineering with UAF, says the company's Quadrafoam air filters allow processors to protect equipment with fire-resistant, cleanable filters. The filters offer low pressure drop and the ability to capture large amounts of airborne dust in industrial enclosure applications. The filters are configured in made-to-size aluminum-framed, permanent-type cleanable units for fresh air intake and exhaust or by themselves in cut-to-size pads. Quadrafoam II air filters are designed for harsh environments and are formulated to withstand prolonged exposure to high-temperature and high-humidity environments, making them long-lasting in industrial applications.

Filtering fluids

There are as many liquid filtering applications as there are chemical processes and while each application has its own set of challenges, there are a few commonalities among them.

For instance, when it comes to cleaning source water as it enters the facility, all processors want as much solids, sand and silt removed from the water as possible, so they are looking for highly efficient solutions in these applications, says Steve Geisel, regional sales manager with Lakos Separators and Filtration Solutions (Fresno, Calif.; www.lakos.com). His company developed the JPX Series (Figure 4) to help solve these problems. This high-performance, liquid-solids separation system uses internal acceleration to achieve maximum protection for fluid handling systems from unwanted solids. The design removes sand, grit and other fine solids from the source of process water and liquid systems, removing 98% of such particles at 200 mesh and larger. With heavier solids, better results can be expected.

The purging/solid-handling concept keeps fluids clean and concentrates separated solids. In addition, there are no screens or filters to clean or replace, which eliminates these types of maintenance expenses.

Geisel says Lakos is launching an even higher efficiency version of this separator called the E-Series later this year. "Since our separators are often in place as a first-pass system, a higher efficiency separator for lower micron contaminants will allow processors to extend the life of the equipment found further downstream, such as polishing filters, secondary filtration systems, pumps or valves," he explains. "This saves money and time on maintenance and equipment costs downstream because the longer the life of the downstream filters and equipment can be extended by keeping them free of solids, the less expensive those systems are to maintain, as well."

Further downstream, filtration for liquid-solid applications, such as latex emulsions and suspended solids, is often plagued with issues such as plugging and chemical or process compatibility, says Mark Rizzone, market manager for industrial processes with Koch Membrane Systems (KMS; Wilmington, Mass.; www.kochmembrane.com). In response, KMS developed its FEG PLUS, cross flow, ultrafiltration technology because it offers a wide pH and temperature range and handles high-suspended solids without plugging. The 1-in.-dia. membrane tubes offer a robust design with good mechanical and chemical resistance properties. Available in neutral or negatively charged PVDF membranes, the technology is suitable for high permeate flux and easy cleaning, which results in fewer interruptions to the workflow, says Rizzone.

Creating new technologies

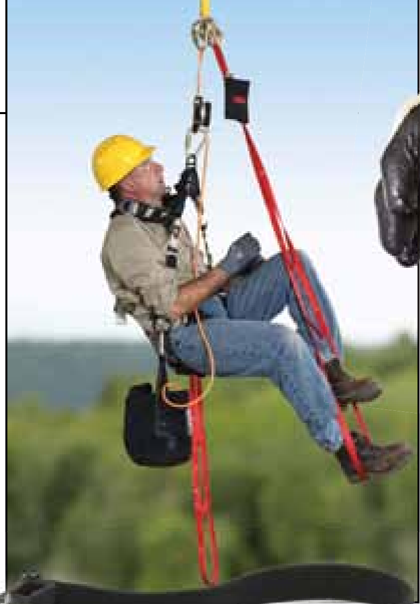
Issues in very specific filtration applications drive, perhaps, the most advanced innovations of all. For example 3M Purification (St. Paul, Minn.; www.3mpurification.com) recently developed the 3M Emphase AEX Hybrid Purifier (Figure 5) for its life science customers in the biopharmaceutical and biologics industries. The technology employs a combination of two types of media (Q-functional nonwoven and sterilizing-grade membrane) that work together to provide improved product purity after clarification in a single-unit operation. The defined pore size of the qualifying membrane provides removal of insoluble particles well below 0.1 µm in size, resulting in superior turbidity reduction. At the same time, the high chromatographic capacity of the Q-functional nonwoven provides substantial reduction of negatively charged, soluble impurities, including DNA and HCP. This combination of attributes allows the hybrid purifier to provide product purity before and, most importantly, after the protein A column to enable a novel and simple post-protein-A mAb purification process.

"We developed this product in response to our customers' need to improve their entire purification process," says Tony Doina, global business unit director for 3M Purification. "This includes extending the life of various chromatography columns, improving protein purity downstream of the columns and extending the life of different membrane filters used in the process. This is a highly regulated industry, which means there are very strict controls of materials and performance of components used, which makes it very expensive. Any time you can extend the life of those individual steps or simplify the process, it is going to provide a cost benefit to the user," he says.

"In addition, proteins are what they are trying to make, so if we can increase the protein purity downstream of the column, it's going to provide an immediate win of an increase in productivity for them," he says Doina. ■

Joy LePree

3M PPE Safety Solutions



FOCUS ON

Personal Protective Equipment

Superior Glove Works

Gateway Safety

Danray Products

Honeywell Safety Products

Escape and rescue kits protect workers exposed to heights

This company has expanded its personal safety portfolio to include a new controlled descent device for escape and rescue at heights, called the 3M and DEUS Escape and Rescue System (photo), that enables workers to steadily descend from heights up to 590 ft. The entire system weighs less than 3 lb and is easy to use, which is crucial in a rescue situation where time is of the essence. The new system is available with two controlled-descent device options: the 3300 device, which allows for rescue from heights up to 350 ft, at a descent rate of 9.8 ft/s, and the 3700 device, which allows a descent rate of 6.6 ft/s from heights up to 590 ft. — *3M PPE Safety Solutions, St. Paul, Minn.*
www.3m.com/ppesafety

Safety gloves with improved finger dexterity

This company has harnessed an advanced knowledge of yarn technology to create an affordable and innovative glove, allowing a broader industrial market of workers to benefit from premium safety solutions. The Dexterity Ultrafine 18-Gauge Cut-Resistant Glove (photo) is said to be incredibly dexterous, making a sleeker fit and improved finger dexterity to allow workers to complete precise tasks requiring agility. The gloves are made with DuPont Kevlar fiber, which combines high dexterity and cut-resistance to keep workers safe while performing tasks that require ultra-lightweight protection. — *Superior Glove Works, Acton, Ont., Canada*
www.superiorglove.com

Outdoor safety goggles designed for winter conditions

Wheelz safety goggles (photo) offer several "cold-weather-friendly" features for outdoor workers in colder climates. They include a unique Whirlwind ventilation system to circulate air through the inner frame area between the face and lens. The resultant strong "whirlwind" of air helps clear the fog and maintain unhindered vision at all times. For additional fog prevention, an anti-fog coating is also available. Wheelz goggles also feature an optional soft foam lining that not only helps with comfort, but also prevents snow and debris from blowing into the eyes. Additionally, mirrored-lens options help fight the glare that is often reflected from snow-covered surfaces. They are independently certified by Underwriters Laboratories (UL) to meet ANSI Z87+ and CSA Z94.3 standards. — *Gateway Safety, Inc., Cleveland, Ohio*
www.gatewaysafety.com

Lathe shields safeguard workers for OSHA and ANSI compliance

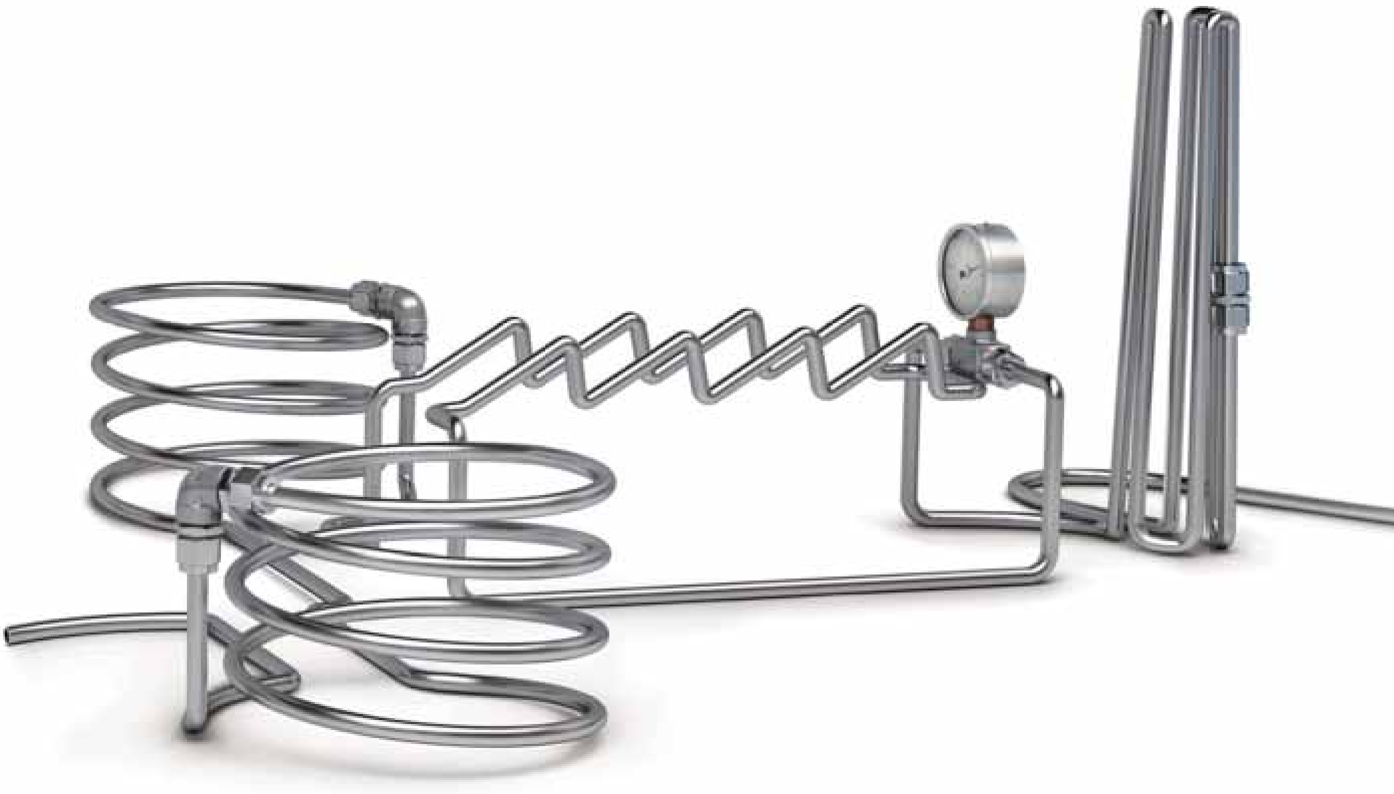
This company offers 52- and 62-in. steel lathe-chuck shields (photo) for lathes or similar machines. These heavy-duty,12-gauge-steellathe-chuck shields serve two basic functions: they provide a safeguard between individuals and point-of-operation or rotating hazards; and they protect individuals from flying chips, sparks, coolant, lubricant and other particles. The mounting bracket attaches to the face of the headstock. The vertical shield hinges like a door, making it easy to change or adjust the chuck or workpiece. These shields comply with OSHA 29 CFR 1910.212 and the ANSI B11.6 safety standard for lathes. — *Danray Products LLC, Rockford, Ill.*
www.danrayproducts.com

Earplugs that provide comfort and hearing protection

The new Howard Leight FirmFit earplugs (photo) feature a softer, more comfortable fit and better noise protection than most leading classic-style foam earplugs. The earplugs are engineered to enhance the wearing experience for individuals who prefer a firmer fit in order to "feel" their earplugs in their ears, and who are accustomed to the familiar cylindrical or barrel-shaped earplug. Independent laboratory tests revealed the new earplugs are 40% softer with 29% lower expansion pressure than most leading classic-style earplugs. They provide effective 30 dB noise-reduction rating (NRR) and are easy to roll down and insert, with plenty of time to adjust for a proper fit. They are bright orange in color for high-visibility and are available in corded and uncorded versions. — *Honeywell Safety Products, Smithfield, R.I.*
www.honeywellsafety.com ■

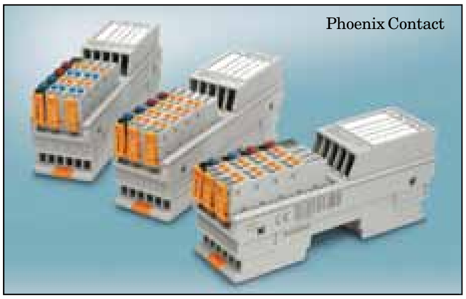
Gerald Ondrey

Note: For more information, circle the 3-digit number on p. 72, or use the website designation.



Flux-Geräte

OCTOBER
New Products



Phoenix Contact

Bürkert Fluid Control Systems

Smith Flow Control USA

Compact I/O modules for the control cabinet

The Axioline F I/O system has been extended with the addition of five particularly compact analog I/O modules (photo). The new modules, which are just 35 mm wide, each offer four channels for tailor-made selection of analog functions in the control-cabinet installation. The product expansion includes two analog input modules and one analog output module for acquiring or outputting voltage and current signals. There are also two new interference-free temperature modules for acquiring signals from standard thermocouples (UTH) as well as from resistance thermometers (RTD). — *Phoenix Contact GmbH & Co. KG, Blomberg, Germany*
www.phoenixcontact.com

This transmitter is available in a new housing version

The modular multichannel multiCELL transmitter/controller type 8619 (photo) is a customizable measuring system with an extended range of functionalities that can work with multiple types of sensors. Previously available only for panel installation, there is now a new, separate housing version that offers more flexibility in installation, for example on walls, railings or pipelines. The new variant can be supplied with a 12–36 V d.c. supply, as before, or alternatively with 110/230 V a.c. supply. The new housing variant is protected according to IP65/IP67, NEMA 4x. — *Bürkert Fluid Control Systems, Ingelfingen, Germany*
www.buerkert.de

This torque-limiting device prevents valve damage

The TorkDrive (photo) prevents manual valves from being damaged due to excessive torque application during valve operation. It can be customized to suit most manufacturer's handwheel-operated valves (including ball, gear, gate and globe) where valves require a torque monitoring of over 59 ft·lb. The device is set to a predetermined maximum torque and if, during the operation of the valve, the operating torque increases above the pre-set limit, the TorkDrive will slip, indicating an irregular valve condition. Following over-torque, the TorkDrive unit will automatically reset to the predetermined torque. Two configurations are available: a low-range unit (maximum torque-output range of 59–206 ft·lb) and a high-range unit (184–309 ft·lb) — *Smith Flow Control USA, Erlanger, Ky.*
www.smithflowcontrol.com

Transferring high-viscosity materials from container drums

The follower plate and process seal of the drum-emptying system Viscoflux mobile (photo) is designed for opening diameters of lidded drums with 560 and 571 mm as standard. During the fluid-transfer process, the process seal adapts to beadings and slight dents. The wall of the drum is stripped so that it is almost entirely residue-free, meaning that residual quantities of less than 1% (less than 2% for drums with aseptic bags) can be achieved. — *Flux-Geräte GmbH, Maulbronn, Germany*
www.flux-pumpen.de

Distributed temperature sensor for infrastructure monitoring

With a 1-m spatial resolution, The DTSX 3000 Distributed Temperature Sensor (photo, p. 31) can measure the temperature along fiber-optic cables up to 50 km in length, eight times the distance possible with the previous model. The DTSX 3000 is well suited for plant and infrastructure maintenance applications that necessitate the monitoring of temperature over long distances or across wide areas. Specific applications include the detection of gas and liquid leaks in tanks and other large production facilities, and the monitoring of conductor temperatures in power lines. — *Yokogawa Corp. of America, Newnan, Ga.*
www.yokogawa.com/us

Verify actuator dimensions with this 3D model generator

This company has developed a new solid-model generator (photo, p. 32) to enable users to generate 3D actuator models that replicate their exact, order-specific configurations. The free service, which allows actuator models to be reviewed from all perspectives before delivery, provides advance verification of actuator requirements during a plant's design phase. Complete actuator systems are shown by the 3D

Note: For more information, circle the 3-digit number on p. 72, or use the website designation.

Yokogawa

models, with all elements detailed, including integrated controls, gearbox and electrical connection. The solid models take up minimal file size and can be integrated directly into the user's CAD environment. All outer dimensions are automatically included, enabling checks to ensure accurate integration and full compatibility with other plant components. — *AUMA Riester GmbH & Co. KG, Müllheim / Baden, Germany*
www.auma.com

Special tools for palletizing containers

The parallel gripper is a special tool for palletizing cardboard boxes and other dimensionally stable containers with parallel side walls. The essential components are a fixed plate that functions as a limit stop and a pneumatically activated clamping device that pushes the cardboard box horizontally against the fixed plate. The suction gripper (photo, p. 32) handles all goods with suctionable surfaces. The suction gripper places its suction head above the product and then lowers the suction head tightly against the product surface. The vacuum pump starts and creates a vacuum in the suction head. Then, the bag is picked up and transported to the target position. Air is released into the suction head and the bag is placed. — *Beumer Group GmbH & Co. KG, Beckum, Germany*
www.beumergroup.com

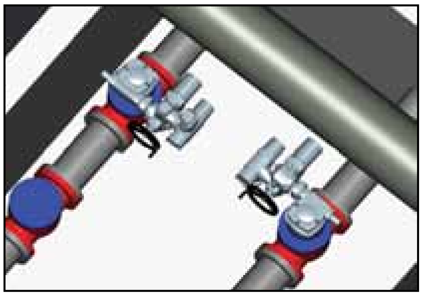
Next-generation wax and resin granulation

The Rotoform 4G — the latest addition to this company's Rotoform range — boasts a number of innovative new features designed to improve productivity and reduce maintenance requirements. The process combines the Rotoform drop depositor with a steel belt cooler to create an efficient and versatile granulation system. Molten product is deposited by the Rotoform onto a continuously running steel belt in the form of measured droplets. As they travel along the system, heat is transferred from the product to cooling water sprayed against the underside of the steel belt, and the droplets solidify into consistently sized pastilles. Among the particular benefits of the Rotoform 4G are easier cleaning and servicing, thanks to

a pneumatically actuated lifting device and new hood design, and improved product quality due to enhanced controls. The design of the Rotoform 4G also enables its use in production lines requiring Good Manufacturing Practice compliance. — *Sandvik Process Systems, Fellbach, Germany*
www.processsystems.sandvik.com


Emerson Process Management

Beumer Group



AUMA Riester

Rotary actuators for internal valves in LPG service
The Fisher P700 series rotary actuators for Fisher C series valves (photo) help to deliver full valve capacity and reduce maintenance in liquid-propane gas (LPG) applications. These actuators offer a reliable method to remotely operate internal valves on storage tanks, delivery trucks and bulk transports. The P700 series actuators assure efficient performance of both the actuator and the Fisher C series internal valve to deliver full valve capacity. The P700 series actuators are compatible with air, nitrogen or propane vapor. They include a ¼-in. UL-approved thermal fuse plug to provide shut-off in the event of an emergency situation and feature a maximum allowable inlet pressure of 8.6 bars. — *Emerson Process Management Regulator Technologies, Inc., McKinney, Tex.*
www.fisherregulators.com ■

Gerald Ondrey

CHEMICAL ENGINEERING
FACTS AT YOUR FINGERTIPS
Department Editor: Scott Jenkins

Forces Acting on a Gasket

Gaskets are relatively simple pieces of equipment in principle, yet are entirely critical in many types of chemical process industries (CPI) applications, including pipes and vessels. An understanding of gasket function, and of the forces and stresses acting on gaskets provides a basis for decisions on gasket types and materials.

Functions and types

Acting as a retaining seal between two rigid stationary surfaces, the gasket material is normally softer than the parts it is sealing, so to some extent, it flows into the irregularities in the joint faces. The gasket will stay seated when the friction between the gasket and the sealing surface is large enough to overcome the pressure exerted on it from the process fluid inside the vessel or pipe.

Gaskets generally fall into two categories: those used in full-faced joints, and those wholly situated within the bolt circle (the circle defined by connecting the centers of the bolts. Since full-faced gaskets have greater surface area, a greater compressive load is required for sealing compared to that used by those within the bolt circle.

Full-faced gaskets are typically used in piping systems with operating pressures up to about 300 psi, while gaskets situated within the bolt circle can be used for pressures as high as 3,000 psi.

Stresses acting on a gasket

A gasket inside a flanged joint is subjected to two opposing forces perpendicular to the plane of the gasket and a sideways force parallel to it (Figure 1). The bolt load (or assembly load) generates compressive stress on the flange to produce a tight seal. The hydrostatic end force acts in the opposite direction and is the product of the working pressure of the flanged joint and the aperture area of the gasket. The difference between these two forces represents the resultant force acting on the gasket, known as the residual gasket load:

Residual gasket load =
bolt load – hydrostatic end force **(1)**

The side force that the gasket experiences, called the blowout pressure, is produced by the internal fluid pressure that pushes to extrude the gasket through the flange-clearance space. The net stress acting on the gasket (per unit area) under operating conditions is known as the residual gasket stress, and is determined by the product of the internal fluid pressure and the gasket factor, *m*:

Residual gasket stress =
m × internal pressure **(2)**

In order for the flange to seal properly, the residual-gasket stress must be greater than the fluid pressure.

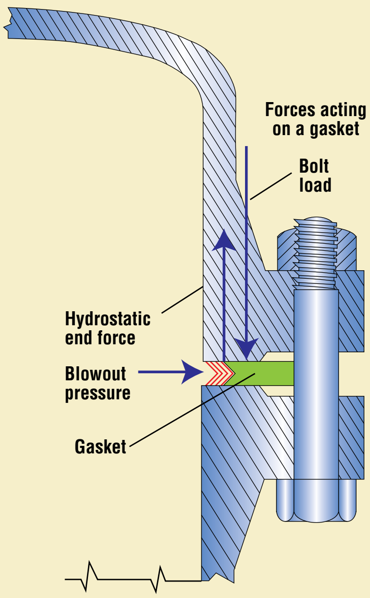


FIGURE 1. In order for a flange to seal, the bolts must be tight enough to overcome the hydraulic end load acting on the flange, while compressing the gasket. The frictional forces of the compressed gasket must be higher than the internal pressure, otherwise it will be extruded through the gap

Y and *m* constants

Design codes for piping systems traditionally classify gasket materials by two factors, *Y* and *m*, which are properties related to the gasket material. The *Y* factor is the initial gasket stress, also known as the minimum design seating stress. Flanges must be designed such that the gasket conforms to the flange surface and be compressed enough initially to eliminate voids and spaces between the flange components. The *Y* quantity, then, is the load acting on the gasket before the system is pressurized.

The *m* factor, sometimes called the maintenance factor is the additional load in the flange fasteners necessary to maintain the compressive load on the gasket once internal fluid pressure is introduced. The *m* factor is defined as the ratio of the residual gasket stress to fluid pressure, which means, from Equations (1) and (2):

m = (bolt load – hydraulic end force)/ (gasket area) × (internal pressure) **(3)**

Most of the pressure-vessel codes have design values for *Y* and *m*. Gasket manufacturers also publish *Y* and *m* values for their own gasket materials and styles.

Seating stress

The total bolt force (F_b) that is required to generate the proper gasket-seating stress is determined by the relation:

$$F_b = N_b \times S_b \times A_b \quad (4)$$

where N_b is the number of bolts, S_b is the bolt stress and A_b is the stress area of the bolt. The value of the total bolt force must be sufficiently high to seat the gasket in to the flange. In most cases, the flange geometry is fixed by design and the inner and outer diameters of the gasket are known. The actual compressive stress available to seat the gasket (S_g) is then

$$S_g = F_b/A_g \quad (5)$$

where A_g is the area of the gasket. The gasket material must be selected so that it will seat satisfactorily under this stress — the gasket material must have a minimum seating stress equal to, or less than, the available stress calculated in Equation 5. The minimum seating stress is normally supplied by the manufacturer of the gasket, and is also available in different design codes.

Material selection

As a rule of thumb, the product of the operating temperature and pressure ($P \times T$) can be used as a general indicator for which type of gasket material to use. Table 1 gives the maximum operating temperature, and the product of operating temperature and pressure, for the three most common general categories for gasket materials. A given material can be considered if the product of $P \times T$ is below the value provided in Table 1.

TABLE 1. RULES OF THUMB FOR GASKET-MATERIAL SELECTION

Gasket material	P x T (psia °F)	Maximum temperature (°F)
Rubber	15,000	300
Graphite foil	250,000	3,000
Metallic	>250,000	(depends on the metal)

References

1. Sahoo, T., Gaskets: The Weakest Link, *Chem. Eng.*, June 2005, pp. 38–40.
2. Ashby, D., Diagnosing Common Causes of Sealing Failures, *Chem. Eng.*, June 2005, pp. 41–45.

Editor's note: Material for the content of this column was adapted from the article in Ref. 1.

Technology Profile

Hydrogen Cyanide Production

By Intratec Solutions

Hydrogen cyanide (HCN) is a chemical precursor used in the production of several industrially relevant compounds, such as adiponitrile for nylon production, methyl methacrylate for polymer manufacturing, sodium cyanide for gold recovery and for the production of methionine, which is used as a feed additive.

HCN is mainly produced though the Andrussow process, named for developer Leonid Andrussow. The method involves reacting ammonia, natural gas and air over a platinum catalyst to form HCN. Alternatively, HCN can be produced by the BMA process, which uses ammonia and natural gas only.

The process

HCN production via the Andrussow process is depicted in Figure 1 and described below, based on information available in the literature. The process can be divided into three main areas: reaction, ammonia recovery and product purification.

Reaction. Natural gas, ammonia and air are fed into the reactor, where HCN is formed through a catalytic reaction. The product stream, containing HCN and unreacted ammonia, must be cooled down to avoid HCN decomposition. This is accomplished in a waste-heat boiler located below the reactor. The waste-heat boiler generates steam that can be used elsewhere in the process.

Ammonia recovery. The product stream is fed to the bottom of the ammonia absorber, where phosphate is used to absorb ammonia. The overhead stream of this column, which contains mainly HCN, is sent to the purification section. The bottoms stream, containing ammonia and a small amount of HCN, is heated and sent to the first HCN stripper.

In this column, HCN is separated in the overheads and recycled to the ammonia absorber. The bottom stream is fed to the top of the ammonia stripper, where phosphate is separated in the bottoms. Part of this stream is mixed with phosphoric acid and recycled to the top of the ammonia absorber. Ammonia, now free of phosphate, is separated as the overhead stream of the ammonia stripper. The ammonia is then directed to the dryer, where it is concentrated and recycled to the reaction section.

Product purification. The HCN-containing stream is fed to the HCN absorber, where HCN is absorbed in cold water. The overhead vent gas is incinerated, since it can still contain some HCN. The bottom stream from the HCN absorber is directed to the second HCN stripper, where the product is separated from water, and then purified in the HCN rectification column to obtain 99.5%-pure HCN product.

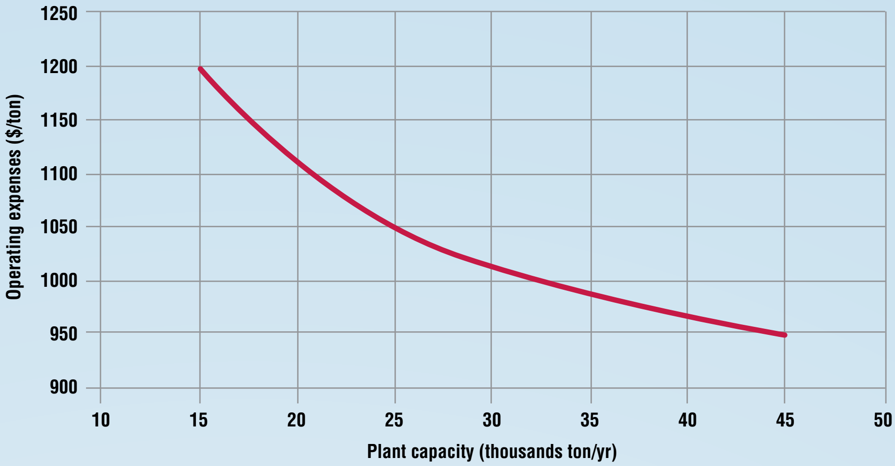


FIGURE 2. Operating expenses for HCN production variation with plant capacity

Economic performance

An economic evaluation of the process was conducted, taking the following assumptions into consideration:

- A 22,800 ton/yr unit erected on the U.S. Gulf Coast (the process equipment is represented in the simplified flowsheet below)
- Outside battery limits units considered are the cooling tower and the refrigeration system
- No storage was considered

The capital investment (including total fixed investment, working capital and other capital expenses) for the construction of this plant is estimated to be about $80 million, while the operating expenses are estimated to be about $1,070 per ton of product. The variation of the operating expenses according to plant capacity is depicted in Figure 2.

Global perspective

HCN is a toxic compound and is dangerous to the environment as well as to human health. Additionally, it is flammable and, if not properly stored, may undergo a polymerization reaction that can be explosive. For these reasons, HCN storage and transportation must be avoided, so HCN is essentially a non-tradable product. Companies that use HCN as a feedstock in their processes must produce it themselves or have it supplied to them by an integrated HCN facility. Also, companies may purchase HCN from nearby acrylonitrile plants that produce it as a byproduct. ■

Editor's Note: The content for this column is supplied by Intratec Solutions LLC (Houston; www.intratec.us) and edited by *Chemical Engineering*. The analyses and models presented herein are prepared on the basis of publicly available and non-confidential information. The information and analysis are the opinions of Intratec and do not represent the point of view of any third parties. More information about the methodology for preparing this type of analysis can be found, along with terms of use, at www.intratec.us/che.

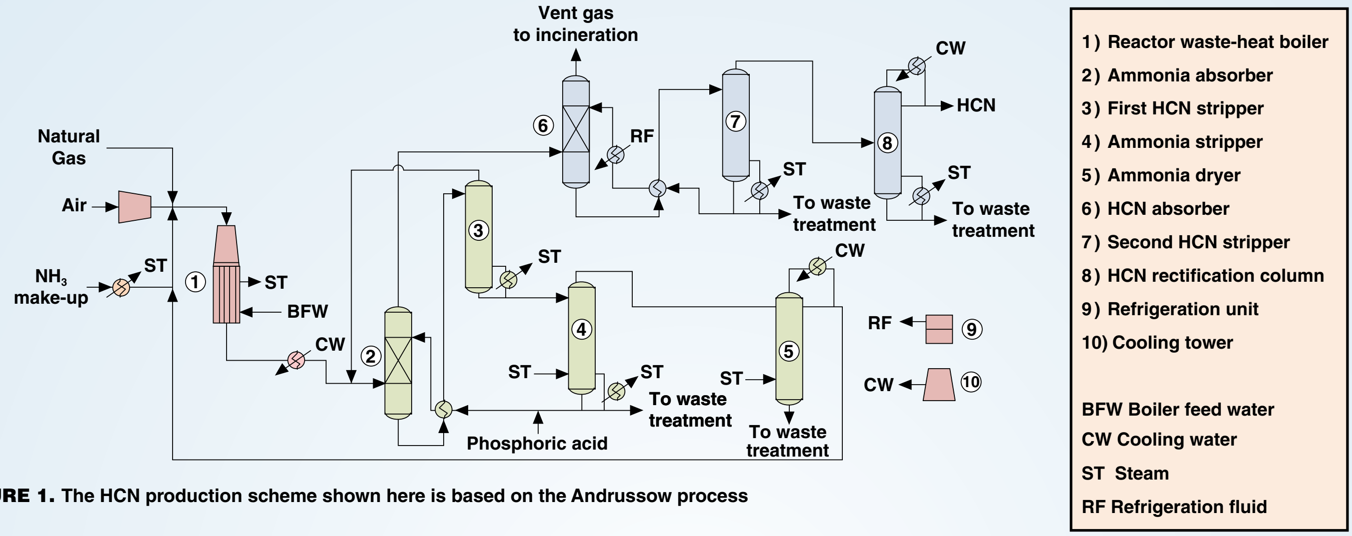


FIGURE 1. The HCN production scheme shown here is based on the Andrussow process

Pressure Transmitter Basics: Selection Guidelines

Climbing the decision tree to pick the right pressure sensor

Wally Baker
Emerson Process Management

What are the steps to finding the best pressure sensor for a particular application? That's a challenge faced by many a young engineer just out of school. Engineering school teaches a great deal of theory, but what is the best way to choose when so many things that affect the decision are not obvious, and not necessarily part of the formal curriculum?

This article reviews a series of questions and other considerations that help guide the engineer in making critical decisions regarding pressure applications. Also, the basic principles of pressure measurement are provided in the box on p 35.

Why measure pressure?

The first question is the most basic: What is the purpose of the measurement? There are generally three reasons for taking a pressure measurement: monitoring, control and safety. While much of the same hardware is used in all three, there are significant differences. The purpose of a monitoring point is to keep the operator informed, but not to close a control loop; this is the least critical of the three. A control point provides an input to a control system, and requires the greatest accuracy, while for a safety point the most important parameters are reliability and keeping users safe.

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FIGURE 1. Pressure transmitters are supplied in many configurations

What pressures are involved?

An important question to ask early on is, what is the normal working pressure? That range of pressure should fall within the device's most accurate range. What are the highest and lowest pressures expected during normal operation? Accuracy can generally degrade somewhat at the extremes, but the device must remain repeatable under these conditions, and must not suffer any damage, nor require recalibration.

It is also vital to know the maximum pressure the device will experience, for safety reasons. It must be able to withstand a pressure as high as the pressure rating of the vessel or pipe to which it is attached without bursting — and that means all attached piping, flanges manifolds and other accessories that will be exposed to pressure must be rated to a minimum threshold. Some devices can continue to operate after such an overpressure incident and retain accuracy, while others may need recalibration or even replacement, but the primary consideration here is safety.

What accuracy is required?

Control applications generally need more accuracy than monitoring applications, while, with safety applications, reliability is key. The exact level of accuracy needed depends entirely on the needs of the process and application being measured.

How to connect to process?

Because pressure transmitters are also used in flow, level or pressure applications, they are often integrated with other components (Figure 1). An in-line mounted transmitter (Figure 2) has a single connection to the process (for gage or absolute pressure) at the bottom of the unit. An in-line mounted transmitter is light in weight and may require no mounting bracket.

A coplanar mounted transmitter (Figure 3) has two process connections for differential pressure (DP) on the bottom of the unit. This transmitter is light in weight and is installed on a single process flange. This connection type is more modern than the biplanar

FIGURE 2. An in-line mounted transmitter has a single connection to the process (for gage or absolute pressure) at the bottom of the unit

PRESSURE MEASUREMENT PRINCIPLES

A pressure transmitter measures the pressure of a gas or liquid and relays that information back to a control system. This differentiates it from a pressure gage, which gives only a local indication and does not communicate.

Gage, absolute or differential?

Any pressure measurement is by definition made against a reference pressure. In a gage measurement (expressed, for example, as pounds per square inch gage, or psig) the reference is ambient atmospheric pressure. An absolute pressure measurement (psia) measures against vacuum, while differential pressure (DP) measures the difference between two pressures.

While the uses of gage and absolute pressure measurements are generally fairly straightforward (what is the pressure in the vessel?), differential pressure measurement has much wider application. It is used in flow measurement, to measure the pressure drop across an orifice plate or other device.

DP is also used in level measurement, to measure the depth of liquid in a tank: if the density of the liquid is known, its depth can be calculated. But since many tanks are not at atmospheric pressure (for many reasons, including the vapor pressure of the liquid in the tank), a DP gage is used, with one side connected near the bottom of the tank and the other near the top, above the surface of the liquid. (For more on DP transmitter applications, see Part 2 on pp. 41–44).

Parts of a pressure transmitter

The major parts of a pressure transmitter are the pressure-sensing element, which transforms pressure input to an electrical signal, an isolating diaphragm and a housing that includes the necessary electrical interfaces.

Sensing element. There are three main types of pressure sensors in common use in these applications. In a *capacitive sensor*, a diaphragm is one plate of an electrical capacitor. An electronic circuit detects changes in the capacitance as the diaphragm flexes under pressure. In a *vibrating wire sensor*, a wire that vibrates at its natural frequency is connected to a diaphragm. Changes in force on the diaphragm change the tension in the wire and hence its frequency. The electronic circuit that drives the vibration detects the change in frequency and outputs it as a pressure reading. In a *piezoresistive sensor*, a strain gage placed on a diaphragm changes its resistance as the diaphragm flexes with pressure changes. In many modern sensors the sensing element is contained on a silicon microchip.

Isolating diaphragm. With the exception of simple applications (measuring the pressure of air or a noncorrosive gas), it is imperative to keep the process medium from reaching the pressure-sensing element. This is most commonly done with an isolating diaphragm. Isolating diaphragms are available in a variety of materials to meet the needs of different process fluids. As pressure is applied to the process, the isolating diaphragm flexes and transfers the pressure to the internal pressure-sensing element via a small volume of oil. The pressure sensor then transforms the pressure input to an electrical signal.

Module housing. The pressure sensor is protected by the module housing, which supports the isolating diaphragms, protects the pressure sensor and provides an electrical connection for the transmitter housing. Transmitter housings are available in three basic configurations for different applications. The *dual-compartment* housing is the most common type. It separates the terminal block from the output electronics. It allows for advanced functionality and allows for use of either an LCD display or a local operator interface. A *single-compartment* transmitter housing is less common. It contains just a wiring termination and junction box housing. A *quick-connect* transmitter housing is compact and lightweight, and simplifies field wiring. ❑

connection. The coplanar connection enables measurement of differential, absolute and gage pressure applications.

A biplanar connection is a more traditional way of connecting to the process (Figure 4) and has two ports on the side of the lower part of the unit. This is the original process connection used for DP measurement; it supports gage, differential and absolute pressure measurements. It is heavier and more challenging to connect than in-line or coplanar designs.

A transmitter used in a DP flow application can also be mounted directly to a flange containing an orifice plate, as shown in Figure 1 (second from the left).

When considering a connection type, one should ask: is there a process connection point available, or will it be necessary to add a connection point or tap into the process? Either of these may require a process shutdown, which can be costly and potentially dangerous. It is also possible to hot tap a process, a procedure that requires highly trained personal, but can keep the process up and running. A new connection is usually put in place during scheduled downtime or if the location can be bypassed.

Other things to consider regarding the connection are as follows:

- Can a flange be added to make the connection? If so, what type of flange is appropriate for the application?
- What threading is present?
- Is a shutoff valve available?

It is often impossible simply to put a pressure measurement point wherever you want it; you can put it in only where access is available. This may be 30 ft down the pipe from where you thought you were going to be able to put it as opposed to putting it right on the vessel itself, and thus may require a remote display to be visible to operators.

All of the mounting considerations for a monitoring point, plus several more, also apply to a control point. For control, you typically will need to have a connection that is more maintainable. There may be sediment buildup, so it is important to be able to clean out and purge the connection point. If a manifold will be needed, it may require more frequent bleeding, which means a bleedable flange will be needed, or a three-way or five-way valve manifold.

It is often a good idea to make sure the final element is close-coupled to minimize buildup of sediment in the connection. In a DP flow application, for example, integrated orifice meters are available (Figure 1, second from the left). Close-couplings also help to minimize leak points. A flush still may be required.

Also, in DP flow applications, it is vital to take flow conditioning into consideration. In retrofits, for example, there is seldom sufficient room for a straight pipe run to reduce the process turbulence in order to make a good pressure reading. In this case, conditioning orifice plates can be utilized. These can make it possible to install orifice plates within a few pipe diameters of an elbow or other feature that would otherwise prevent laminar flow.

Wet leg or wet-leg/dry-leg?

Traditional DP measurement requires impulse piping connected to the high- and low-pressure sides of the process vessel or tank. In the traditional wet-leg/dry-leg arrangement used for measuring level in vessels and tanks, the high pressure side (the wet leg) is filled with process fluid, while the impulse line on the low pressure or reference side (dry leg) is filled with vapor (although it can also be filled with a non-reactive gas).

In gas service, the process tap should be on the top side of the pipe, and the transmitter mounted above the pipe, with the impulse line (the dry leg) sloping upward; this is to make sure that any condensation in the impulse line will drain back to the main pipe. In liquid service, the situation is reversed; the tap should be on the bottom of the pipe, the transmitter mounted below, and the impulse line (the wet leg) sloping down to it, so any gas in the impulse line can get back to the pipe.

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FIGURE 3. **A coplanar mounted transmitter has two process connections (for differential pressure) on the bottom of the unit**

In steam flow service, the impulse lines are kept filled with condensate, to keep hot steam from reaching and damaging the transmitter. In cold areas, these impulse lines require insulation and heat tracing to prevent freezing damage from condensate. This is expensive and can be a maintenance concern.

A wet leg requires a constant level of liquid within the tubing for a reliable measurement. If the liquid evaporates, the DP measurement will drift.

A dry leg must be kept free of condensation. If process vapors condense into the dry-leg tubing, the DP measurement will drift.

Evaporation or freezing of the liquid in the wet leg and condensation in the dry leg can hurt accuracy and requires a fair amount of maintenance. One solution for steam service in cold climates is to replace the separate orifice plate and DP meter with a single device combining the element (generally either an averaging Pitot tube, for example an Annubar, or a compact wafer-style primary element with the orifice plate integrated with the manifold) with the DP transmitter mounted above the steam line. This eliminates the impulse lines and solves the freezing problem.

For food-and-beverage applications, process material can be trapped in the impulse lines and allow bacteria to grow. In other cases the process material may tend to cause plugging in the impulse lines.

Remote seals

One solution to plugged impulse lines is often a remote seal and capillary system (also known as a chemical seal, diaphragm protector or diaphragm seal system; Figure 5). This consists of an external sensing diaphragm. Process pressure is transmitted to the pressure sensor via an oil-filled capillary. The system acts as an extension of the pressure transmitter and protects the transmitter diaphragm from hot, cold or corrosive processes, as well as viscous materials or those containing suspended solids that might plug impulse piping. In hygienic applications, remote seals also allow for easier cleaning of the process from the connections to avoid contamination between batches. And it avoids maintenance often needed with wet-leg and dry-leg installations.

There are also electronic remote-sensor arrangements for measuring tank level. Instead of having a single DP transmitter installed with connections to the bottom and top of the tank (the former for measuring the level and the latter to provide the reference pressure), two transmitters are used. One is located at the bottom of the tank, with the other one at the top. The two sensors are connected electronically, instead of mechanically, via a wet-leg/dry-leg or capillary (Figure 6). This is useful for tall tanks because it eliminates the need for long impulse lines. A caveat to this method is that accuracy is impacted in tanks with high blanket pressures relative to the DP measurement for level. When considering such an arrangement, it is best to consult a factory expert to help select the best technology.

Environmental considerations

Operating temperature is a vital consideration. If using a remote seal system, be sure to choose a fill fluid compatible with both the process temperature and the ambient temperature. At low temperatures, impulse lines can freeze, or the fill fluid can gel. At high temperatures, the fill oil in a remote seal system can boil or degrade. There are fill fluids that can withstand high temperatures, but some of these have limited low-temperature ranges.

Will there be significant mechanical vibration? Transmitters should always be installed to minimize vibration, shock and temperature fluctuations.

Does the process involve significant pressure pulsation (for example, at the discharge end of a positive-displacement pump)? Rapid pulsation degrades measurement accuracy and, if it continues for long periods, can wear out the pressure-sensing element. A pulsation damper or snubber may be required. This can be as simple as a porous metal filter or an adjustable needle valve inserted in the impulse piping. In general, strain gage and capacitive sensors are more resistant than other types to the wear and tear from highly pulsating processes.

Will the device be used in a hazardous area? If so, what approvals will be required? Relevant approvals can include ATEX, IECEx, CSA and Factory Mutual (FM), for starters. Many devices are available with combination approvals that make them suitable for a variety of hazardous areas.

In food-and-beverage and pharmaceutical applications, remember that the transmitter may be subjected to spraydown/washdown with hot and aggressive chemicals, and must be rated for such service.

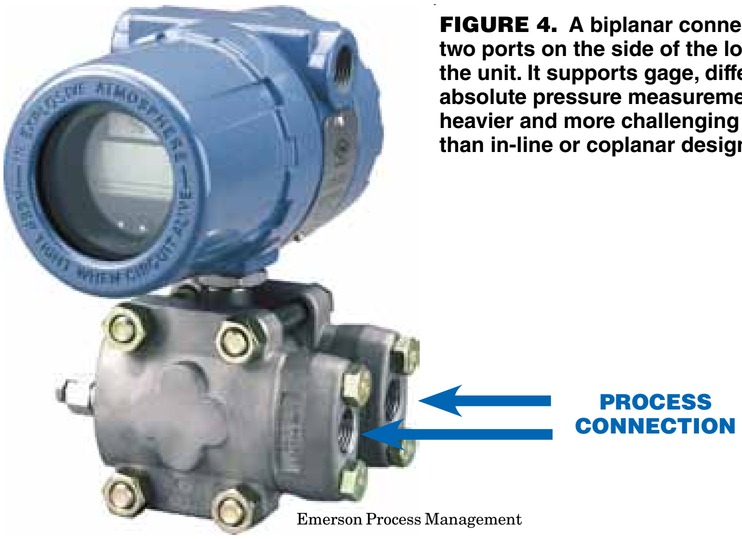

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FIGURE 4. A biplanar connection has two ports on the side of the lower part of the unit. It supports gage, differential and absolute pressure measurements. It is heavier and more challenging to connect than in-line or coplanar designs

Maintenance considerations

It is important to know how often the transmitter will need recalibration, and what will be involved in doing that. It may require that the device be physically removed and sent to an instrument laboratory, which, depending on the way it is installed, may require a process shutdown. If the transmitter can be isolated with shutoff valves, the disruption will be considerably reduced. In addition, some transmitters now can offer longer stability specifications, thus reducing maintenance costs in some applications since they require fewer calibrations.

Intelligent transmitters

Many of today's intelligent process transmitters contain a great deal more information than simply the pressure reading; this can include temperature, the device history, range-setting information and more. An intelligent transmitter can detect internal problems, allow the unit to be recalibrated and re-ranged remotely and in some cases even spot process anomalies and plugging of the impulse lines. Some interesting work is being done based on using the raw, high-speed data coming directly from the transmitter's sensing element before it is smoothed and filtered for delivery to the control system. There are a number of ways this additional information can be made available, as discussed below.

Choices of transmission media

Analog. The simplest and most common way for a transmitter to deliver its output is analog, via a 4–20-mA current loop: 4 mA indicates the bottom of the device's range and 20 mA the top; the 4 mA value is used to ensure that zero current will be seen as an indication of loop failure, not a reading of zero; the 4 mA is also sufficient to power the transmitter. There have been, and are, some competing analog standards, like 10–50 mA (now obsolete) and 0–20 mA, but they are seldom seen. There are 1–5-V systems, but they are used in only a few applications, such as low-power installations.

Use of a current loop requires that each transmitter have its own wire pair leading back to the control room (a distance that can reach a mile or more, in some facilities), plus its own input point in the control system, which adds significantly to the cost of adding additional measurement points to a facility.

HART. There is much more information available in today's transmitters than just the process variable output, and in the 1980s the HART (Highway Addressable Remote Transducer) protocol became available. HART superimposes a small alternating component on the 4–20-mA output, with information carried by frequency-shift keying: 1,200 Hz indicates a digital 1 and 2,200 Hz represents a 0. Since this carrier signal sums to zero over time, it has no effect on the 4–20-mA loop. The HART signal allows two-way communication between the control system (the "master," in networking terminology) and the transmitter (the "slave") at a speed of 1,200 bits/s. As stated by the HART Foundation (Austin, Tex.; www.hartcomm.org), which controls the specification, "The digital signal contains information from the device including device status, diagnostics, additional measured or calculated values, [and so on]. Together, the two communication channels provide a low-cost and very robust complete field communication solution that is easy to use and configure." [*1*] A handheld communicator can also be connected to a transmitter for local setup and maintenance purposes.

HART has the advantage of using the existing 4–20-mA field wiring, which makes it simple and inexpensive to set up. But this is also a disadvantage. Because HART uses a separate 4–20-mA loop for each transmitter, it is expensive to add additional transmitters to an existing system.

There is also a multidropped version of HART in which there are no 4–20-mA loops; all transmitters connect to the same cable, which carries sufficient current to provide 4 mA to power all the connected devices, and all process-variable data are sent digitally in response to interrogations from the master; though this architecture is seldom utilized. A wireless-HART protocol is also available, as discussed later in the article.

Digital fieldbuses. Since the mid-1980s, numerous networks that can be classified in computer terms as local area networks have been introduced; currently in the process control field the most popular are Foundation Fieldbus and Profibus PA. There are many others used in discrete control applications and office communications, including Ethernet, MAP, CANbus and more, but these are outside the scope of this article.

FIGURE 5. A remote seal and capillary system consists of external sensing diaphragms (which can be flush or extended, as shown) mounted to the process and connected to the DP transmitter either directly or via oil-filled capillaries

Digital fieldbuses make available a great deal of information inside the connected field devices; this can greatly speed diagnostics. But one of the biggest advantages of digital field buses is that they greatly reduce the expense of adding additional field devices; because field devices are tapped into a single cable, the cost of a separate cable for each field device is eliminated.

Foundation Fieldbus. Foundation Fieldbus is controlled by the Fieldbus Foundation (Austin, Tex.; www.fieldbus.org). While there are two versions of Foundation Fieldbus (with more on the way), the one used in process control applications, and the most common implementation for transmitters is an H1 segment design. This uses a two-conductor cable with devices multidropped from it, and is entirely digital. It uses a peer-to-peer protocol: devices can communicate with each other without a host, and they can initiate communications without a specific host command. For example, if one device experiences a problem, it can send an alarm.

Because Foundation Fieldbus uses a peer-to-peer protocol, individual devices (valve actuators, for example) can contain control software (function blocks) and make decisions based on data from other field devices. This makes it possible to set up truly distributed control, often called control in the field, although such arrangements should be attempted only by those with a great deal of experience.

Profibus. Profibus is controlled by Profibus and Profinet International (PI; Karlsruhe, Germany; www.profibus.com). Like Foundation Fieldbus, Profibus' devices are multidropped from a two-conductor cable. There are several versions of Profibus for different purposes; the one most used in the process industries for transmitters is Profibus-PA (The name Profibus originally meant Process Field Bus, and the PA is for Process Automation). Profibus-PA uses a master/slave protocol: individual devices respond only when interrogated by the central master.

Both Foundation Fieldbus H1 and Profibus-PA provide a data rate of 31.25 kbits/s, have a maximum cable length of 1,900 m, and can support up to 32 devices per cable segment; though often device counts are much lower on the segment to support hazardous-area installations as well as bandwidth and expansion requirements. Power is supplied to the field devices over the cable.

Have you considered wireless?

One way to substantially reduce wiring costs for transmitters is to skip all wired connections, analog or digital, and use a wireless system. Alternatively, wireless can be used to add capabilities to an existing wired system: While HART is an industry standard, of the 30 million wired installed HART instruments, less than 10% have remote access to secondary data (checking and re-ranging are done with handheld units). There are now wireless adaptors that can be plugged into a HART-equipped 4–20-mA transmitter and make it part of a wireless network, unlocking configuration data, status information, calibration dates, and process data, both the main PV output and internal data like temperature — without

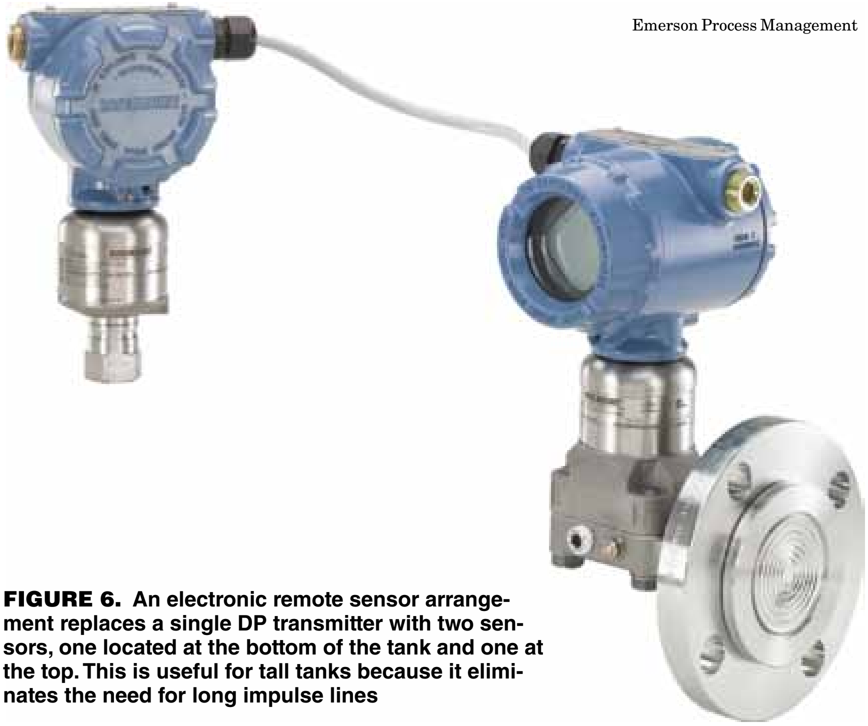
Emerson Process Management

FIGURE 6. An electronic remote sensor arrangement replaces a single DP transmitter with two sensors, one located at the bottom of the tank and one at the top. This is useful for tall tanks because it eliminates the need for long impulse lines

having to walk out to the transmitter to check it.

WirelessHART. While the first wireless networks in plants were almost exclusively for asset monitoring purposes, the advent of IEC 62591 (WirelessHART) made wireless delivery of process-variable information increasingly common for monitoring and control applications.

An IEC-approved WirelessHART system takes the form of a self-organizing mesh network, with a wireless gateway as its connection point to the plant's main control system. Each transmitter constitutes a network node that acts as both a source of data and as a router, so that a message from one node will be passed from node to node until it reaches the gateway, and a message from the gateway to a particular node will similarly be passed via multiple paths in the mesh from node to node until it reaches its intended recipient. The redundant paths provide for reliable communications; not dependent on a single path for communication. The network is also self-healing: if one node is disabled, network traffic will be automatically routed around it to ensure delivery. The arrangement also allows the network to extend over a larger geographic area than the radio range of the individual nodes. A node does not have to be within radio range of the gateway, it just has to be in range of one or two other nodes in the system.

Advantages. One of the major advantage of wireless is that it does not require any new I/O points. Expanding a plant, or just adding transmitters to an existing system, generally requires a new I/O. A wireless network makes it possible to expand a plant's instrumentation without running any wiring at all (4–20 mA or even fieldbus cabling). One simply connects the gateway to the control system. The additional wireless transmitters can be battery-powered and exist as nodes on the wireless mesh network adding the required process information.

Data rates. While wired HART operates at 1,200 bits/s, IEC 62591 (WirelessHART) operates at 250 kbits/s, although the rate at which data are delivered over time is considerably slower. This is because a WirelessHART transmitter does not send data continuously; to do so would quickly exhaust the battery of a battery-powered unit.

For many networks, an update rate of several times per minute is sufficient, and can allow battery life from months to years. In some applications (tank-farm-level monitoring, for example), the update rate can be even lower under most conditions. And for such applications with slowly changing variables it is possible to include the wireless link as part of a control loop. Some wireless devices can update at a rate of once per second, which can be similar to some wired devices.

Some final thoughts

As in any field, there are many things to consider when it comes to selecting a pressure transmitter. Many of these considerations are not covered in engineering school, and are best learned on the job — preferably, by learning from more experienced engineers.

One way to get a great deal of helpful information is to ask an application engineer from a major instrumentation vendor; many of these people have upwards of 30 years of experience in the field, and have seen and dealt with situations beginners have not imagined. They can often provide what amounts to free consulting services in terms of technology selection. We hope that this article will help you know what questions to ask. ■

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Pressure Transmitter Basics: DP Transmitters

How a variety of process parameters can be measured with DP transmitters

Roberto Zucchi and Bill Simpson
ABB Measurement Products

Pressure transmitters are widely used throughout the chemical process industries (CPI). Although pressure in and of itself is an important process parameter, differential pressure (DP) measurements enable the inference of other important parameters as well. This article presents a concise overview of how DP transmitters can be put to work in CPI plants.

DEFINITIONS

Here are some important common terms and their definitions. For additional general information on pressure transmitters, see Part 1 on pp. 34–39:

Atmospheric (barometric) pressure. This is the pressure that is exerted by the atmosphere surrounding the earth. Atmospheric pressure at sea level equals 14.695 psia. This value decreases with increasing altitude.

Hydrostatic pressure. Hydrostatic pressure is encountered in liquid level applications. It is the pressure below the liquid surface exerted by the liquid above.

Line, static or working pressure. Static pressure is the force per unit area exerted on a surface by the flow parallel to a pipe wall.

Absolute pressure. Absolute pressure is a measurement referenced to a full, or perfect vacuum. Zero absolute pressure (0 psia) represents a total lack of pressure, such as occurs in outer space.

Gage pressure. Gage pressure is a measurement referenced to atmospheric pressure. Gage pressure represents the positive difference between measured pressure and ambient atmospheric pressure. One can convert gage pressure to absolute pressure by adding the actual atmospheric pressure value to the gage pressure reading. For example 10 psig is equivalent to (10 + 14.7 psia) or 24.7 psia at sea level.

Vacuum pressure. A vacuum pressure measurement is referenced to atmospheric pressure, but below it. The units of vacuum pressure are generally centimeters or inches of water (in. H_2O). For example, 14.7 psia equates to 407.5 in. H_2O. So a pressure of 10 in. H_2O vacuum would be equivalent to 397.5 in. H_2O absolute. Vacuum pressure is typically measured using a gage pressure transmitter with an elevated zero calibration. ❏

Versatility of DP measurements

DP transmitters are highly useful for determining the value of multiple chemical plant variables, such as differential pressure, flowrate, level and density. These transmitters have two pressure ports (high and low) and can measure gage pressure (see definitions in box above), absolute pressure and the difference between two pressures (differential pressure or DP). If the low-pressure (LP) port connects to vacuum, the high-pressure (HP) port measures absolute pressure. If the LP port connects to the ambient atmosphere, the other measures gage pressure. Otherwise the transmitter simply measures DP, the difference in pressure connected between the two ports.

Flow. DP transmitters are commonly used to measure fluid flowrate through a pipe. A primary flow element, such as an orifice within the pipe (Figure 1), reduces the cross sectional area through which the process fluid flows. This restriction increases the fluid velocity through it, increasing its kinetic energy. Other types of common restrictions include Venturi flow elements, nozzles, wedges and flow tubes.

Conservation of energy requires the downstream side of the restriction to drop in line or static pressure. Taps placed on either side of the restriction see a differential in static pressure. A pressure transmitter connected to the taps measures this differential pressure, which can be related to the volumetric flowrate of the fluid.

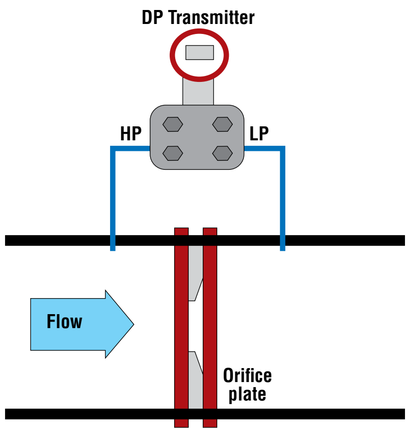

FIGURE 1. A DP transmitter can be configured to measure flowrate

This differential pressure does not vary linearly with the flowrate, but with its square root. Industrial DP pressure transmitters are generally capable of performing the arithmetic conversion to make the output signal linear with flowrate. But this limits the range ability of these kind of flow measurement. In the case of an orifice, for example, the range ability may be five to one.

Liquid level. A DP pressure transmitter can measure the level of liquid in a tank, whether open or closed. In the case of an open tank (Figure 2, left), the pressure of the liquid in the tank at any depth depends directly on the depth value and the liquid density. So if the HP port of a DP transmitter connects

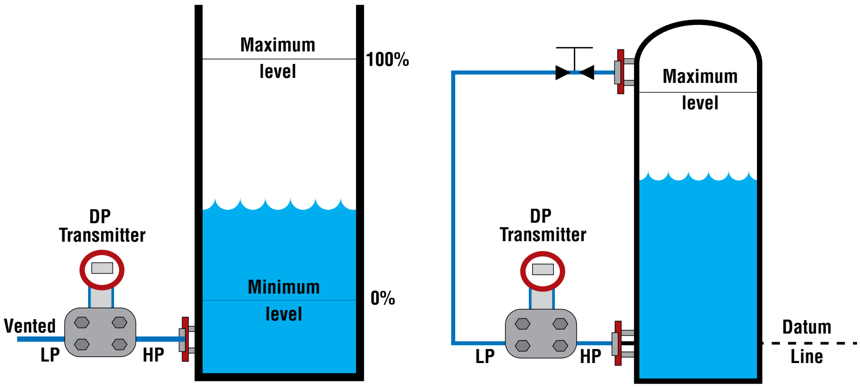

FIGURE 2. A DP transmitter can be used to measure the liquid level in either an open (left) or closed (right) tank or vessel

to a tap at the bottom of the tank and the LP port to atmosphere, the output signal can be related to the tank liquid level.

Since the tank is open, any change in the atmospheric pressure affects pressures within the tank liquid. But the LP port of the pressure transmitter also connects to atmosphere, cancelling out the effects of atmospheric pressure on the open tank fluid level. The liquid density must be constant or be accounted for.

In the case of a closed tank or vessel that is sealed from the atmosphere (Figure 2, right), the low-pressure side of the transmitter can be piped to the top of the tank rather than to atmosphere. Otherwise, when a process fluid fills or leaves a closed tank, the pressure inside may go from positive to vacuum, which would adversely affect the level measurement. Connecting the LP port of the transmitter to the tank top easily compensates for any changes in tank pressures.

A bubble tube of pipe offers another way to measure liquid level with a DP transmitter in open and closed tanks (Figure 3). A tube inserted into the tank maintains a constant pressure of air or some gas compatible with the tank contents. As the liquid level changes, the backpressure measured by the transmitter directly corresponds to the tank level. The advantage here is that only the tube or pipe material comes in contact with the process liquid — not the pressure transmitter. A second advantage here is that it requires no connections to the bottom of the vessel. However, the process liquid cannot be sensitive to the gas bubbling through it. A disadvantage is that a source of air pressure is required.

Level calculations. To calculate the pressure at the bottom of the tank in Figure 3, you must know the value of h, the distance from the liquid level to the end of the bubble tube. For example, if h is 50 in., and the material in the tank is water, then we can express the pressure at the bottom as 50 in. H_2O or about 1.8 psig. But if the liquid in the tank is not water, a conversion must be made to specify in inches of H_2O.

The formula for this conversion is:

$$h = h' \times SG \qquad (1)$$

Where:
h = liquid head, in. H_2O
h' = actual liquid head, in.
SG = specific gravity (dimensionless) of the fluid in the tank

Recall that specific gravity is the relative weight of a unit volume of liquid compared to the same volume of water. Gasoline, for example, has an SG of about 0.8. So a gallon of gasoline weighs 80% of the weight of a gallon of water. The point is that you must consider the liquid's density when measuring liquid level with a DP transmitter.

Interface level measurement. Figure 4 shows a technique for measuring the level of the interface between two liquids of different densities, such as oil and water. The total level in the tank must remain above the top tap of the DP transmitter and the distance h must be constant. As the interface level changes, the lower tap sees a density change along with a corresponding change in the hydrostatic pressure. Newer methods of performing this measurement have evolved in the relatively recent past.

Density. From the discussion above, it follows that if the liquid in the tank of Figure 5 is homogenous, then any changes in the process liquid density will be reflected as a change in static pressure. Again, as long as tank level remains above the top pressure-transmitter tap and as long as the distance between LP and HP sensors, h, is constant, the transmitter will respond linearly to changes in density. Typically, as in level measurement, chemical plants use a sensitive DP transmitter because the spans are relatively small.

Remote seals

Generally, the sensing element within a DP transmitter comes in direct contact with the process fluid. The sensing element, such as a diaphragm within the transmitter, responds to the force created by the process fluid pressure. An associated sensor generates a low-level

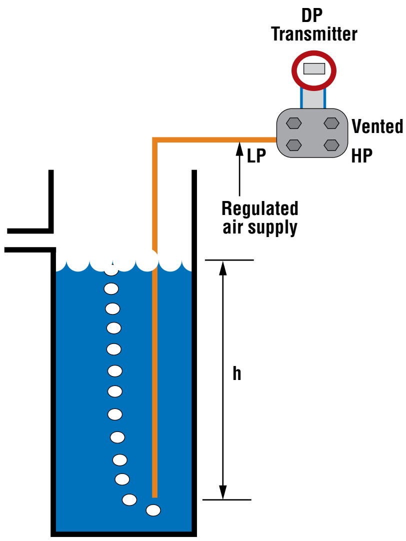

FIGURE 3. Liquid level can also be determined using a bubble tube

electronic signal related to flexing of the diaphragm. A secondary electronic package acts on this signal, producing a standard transmission signal, such as 4–20 mA. Remote seals have been developed to widen the applicability of the DP pressure transmitter beyond its limitations of maximum temperature and dirty, corrosive or abrasive process fluids.

The term "remote seal" refers to an isolation seal system that protects a pressure transmitter sensor and its process connections from any contact with the measured process fluid. The seal is called "remote" because it permits the transmitter to be located up to some 80 ft from the element connections. Sometimes the transmitter is close-coupled to the process pipe or vessel. Seals in such cases would be more aptly called isolating seals. Other names used are diaphragm seals and chemical seals.

The remote or isolating seal system constitutes a well-engineered, useful accessory, usually ordered in pairs as integral transmitter attachments, and sized for a specific application. The system consists of a flange connection, a stem, and a seal diaphragm connected through a capillary to the flanged chamber of the transmitter. Shown schematically in Figure 6, the seal has two main components: a flexible metallic diaphragm that is exposed to the process fluid and reflects its static pressure plus a liquid-filled capillary tube that connects to the transmitter body.

Seal systems come with a variety of diaphragm diameters, materials and configurations to suit needs of the installation. In some cases the capillary is protected with suitable armor.

Once the individual components are connected, a technician evacuates the air from the system and fills it with an incompressible fluid. In this way when the seal diaphragm experiences process pressure, it deflects and exerts a force against the fill fluid. Since the liquid is incompressible, this force is transmitted hydraulically to the sensing diaphragm within the transmitter body, causing it to deflect in turn. The deflection of the sensing diaphragm of the transmitter is the basis for the pressure measurement.

Specifying remote seals

Certain considerations affect the proper dimensioning of a remote seal system. For one, a full-scale deflection of the seal diaphragm must exceed the displacement capacity within the transmitter; otherwise the seal element cannot drive the transmitter to a full-scale measurement. Additionally, best practice is to minimize the volume of the capillary fill cavity between the seal flange and the primary diaphragm of the transmitter. This minimizes the ambient and process temperature effects on the measurement. Special flanges are available for the transmitters that minimize the cavity volume when connected to a remote seal.

Response time. Engineers must consider the response-time issues when specifying a remote seal. The time constant for a measurement is the time required for an instrument output to reach 63% of the value it will ultimately reach in response to a step change in input (pressure in this case). Normally an instrument will reach 99.9% of full response within a time equal to four times the time constant.

The response time of a DP or gage pressure transmitter can significantly increase when connected to a remote seal. This response time depends on the following:

- The total length of capillary connecting the seal element to the transmitter body: The response time is directly proportional to the length of capillary. So the length of capillary has to be min-

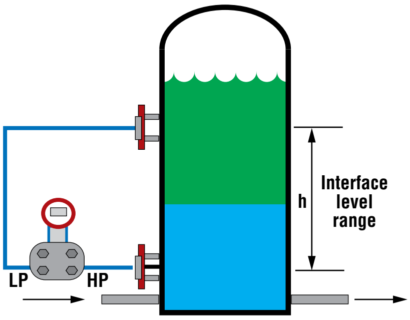

FIGURE 4. The interface between two liquids of different density can be measured with a DP transmitter

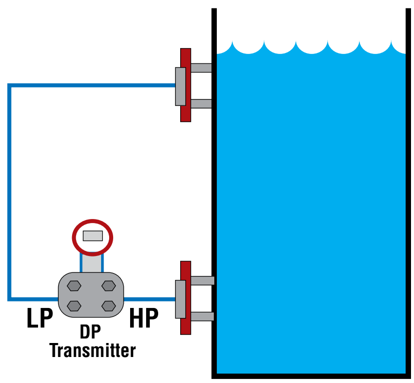

FIGURE 5. Changes in a fluid's density can be monitored with a DP transmitter

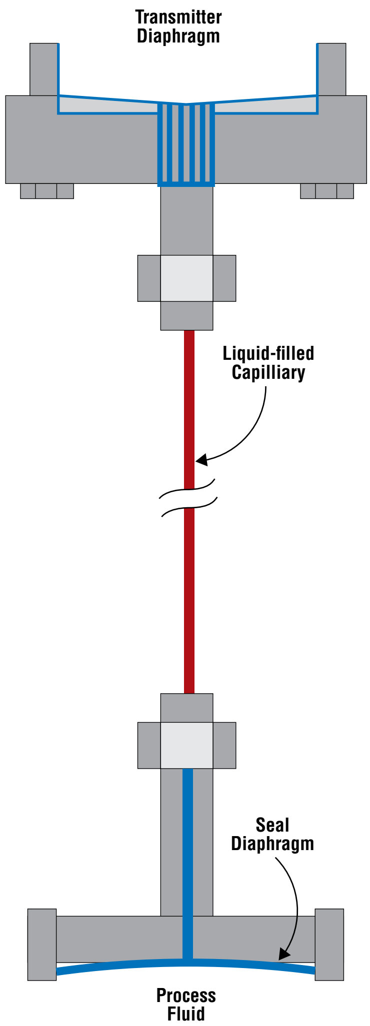

FIGURE 6. A remote (isolation) seal configuration enables a broader range of applications for a DP transmitter

imized provided that the application requirements are satisfied

- The inside diameter of the capillary: The response time of the instrument is inversely proportional to the fourth power of the capillary diameter. A smaller capillary section delays the response
- The viscosity of the fill fluid: Obviously a high-viscosity fill fluid increases the time it will take that fluid to transmit an applied force through the system. Also the temperature effect on viscosity (generally the viscosity increases as temperature decreases) must be considered. As the average temperature along the length of the capillary decreases, the system response time lengthens

Temperature effects. Another key consideration when specifying remote seals relates to temperature. The temperature under which the remote seal system was filled is called the reference temperature. Any difference in temperature from this reference that the capillary experiences will cause the fill fluid to expand or contract. The resulting magnitude of the effect depends on the physical properties of the actual fill fluid. The change in volume causes the internal pressure of the system to change. This will in turn cause a deflection in the transmitter diaphragm, which leads to zero shifts and measurement errors.

After installation, this effect can be "zeroed out." However each time a temperature variation in the process or ambient temperature affects the temperature of the remote seal components, a zero shift or measurement error will be induced.

The adverse temperature effects can cancel in the case of a differential-pressure measurement with two remote seals having the same dimensions, including the capillary length. If both branches of the DP transmitter experience the same temperature, the temperature effects compensate each other, minimizing the error.

Another way to attenuate temperature effects is to choose a seal diaphragm with a high spring rate. The spring rate (or flexibility) depends strictly on the diaphragm diameter, thickness, pattern and the material elasticity. The hydraulic circuit of a diaphragm-seal system is a closed volume where fill-fluid expansion causes an increase of the internal circuit pressure. The higher the diaphragm seal spring rate, the more the fill fluid expansion will be absorbed by the diaphragm. Diaphragms with higher spring rates produce a smaller applied pressure increase as a result of a temperature increase. Increasing the diameter of the seal diaphragm increases its spring rate. High spring rates are also recommended for measuring very low pressure spans, as they can withstand only small volumetric changes in fill fluid.

The installation dictates the length of the capillaries. Response times can be decreased by enlarging the capillary internal diameters. But this, together with the length of capillary, increases the total volume of the filling fluid with negative temperature effects. So some trade-off between response time and optimal temperature performance must be accepted.

Fill-fluid temperature effects. On level measurement applications where the distance from tap to tap is long (greater than 20 ft), an additional temperature effect, called the head effect, must be considered. The head effect relates to the change in specific gravity of the capillary fill fluid caused by temperature variation. For example, the silicon oil commonly used as a filling media has a certain specific gravity at 68°F. When the ambient temperature increases, the specific gravity decreases.

The pressure generated by the hydrostatic column of the fill fluid inside the capillary changes with temperature and its value increases proportionally to the tap distance. Changes in ambient temperature cause the expansion of the fill fluid, which generates a higher internal system pressure. The head effect instead generates a pressure reduction in the system.

Instrument engineers reduce head temperature effects by tailoring the construction of the diaphragm seal system to the real operating conditions of the installation. Typically, a DP transmitter with a direct-mount diaphragm isolation seal exists on the high-pressure side (at the bottom of the tank) with a remote diaphragm seal on the low-pressure side (topside of the tank). Engineers select customized diaphragm spring rates to create an error which is opposed to the one generated by the head effect.

This compensates the transmitter to eliminate the head effect, which will be virtually neutralized by a stiffer diaphragm used on the low-pressure side. These tailored systems can optimize DP level measurements even in deep tanks with very high hydraulic pressures. Otherwise, the remote seals would generate large errors.

Application range

Pressure transmitters come configured for very low to very high pressure ranges, as well as with materials to resist corrosion and chemical reaction. In addition, remote and isolation seals and filled capillaries may be used to isolate the transmitter's pressure diaphragm from the chemical process. Diamond-hard coatings for the pressure diaphragm can resist abrasive action. ■

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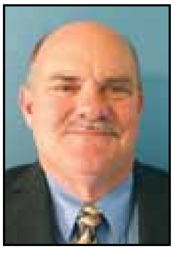
Authors



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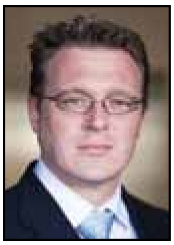

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Reactive Chemistry in the CPI

Improper handling of reactive chemicals can result in catastrophic industrial disasters, and a clear understanding of these materials is essential for safe process-design practices

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Reactive chemicals and intermediates are used extensively in the chemical process industries (CPI). Hazardous chemical reactivity can be defined as "any chemical reaction with the potential to exhibit rates of increase in temperature and/or pressure too high to be absorbed by the environment surrounding the system" [*1*]. Reactive materials can be classified into two groups: self-reacting materials and materials that react with other materials.

Understanding the reactivity of these chemicals and the hazards they pose is an essential part of process safety. Under normal storage and ambient conditions, most chemicals maintain stability. However, process deviations, sudden changes in the operating conditions or contact with other chemicals may destabilize a chemical, releasing large amounts of energy and leading to a hazardous event. The resulting incident, generally characterized by fire and explosions, can lead to loss of life and property.

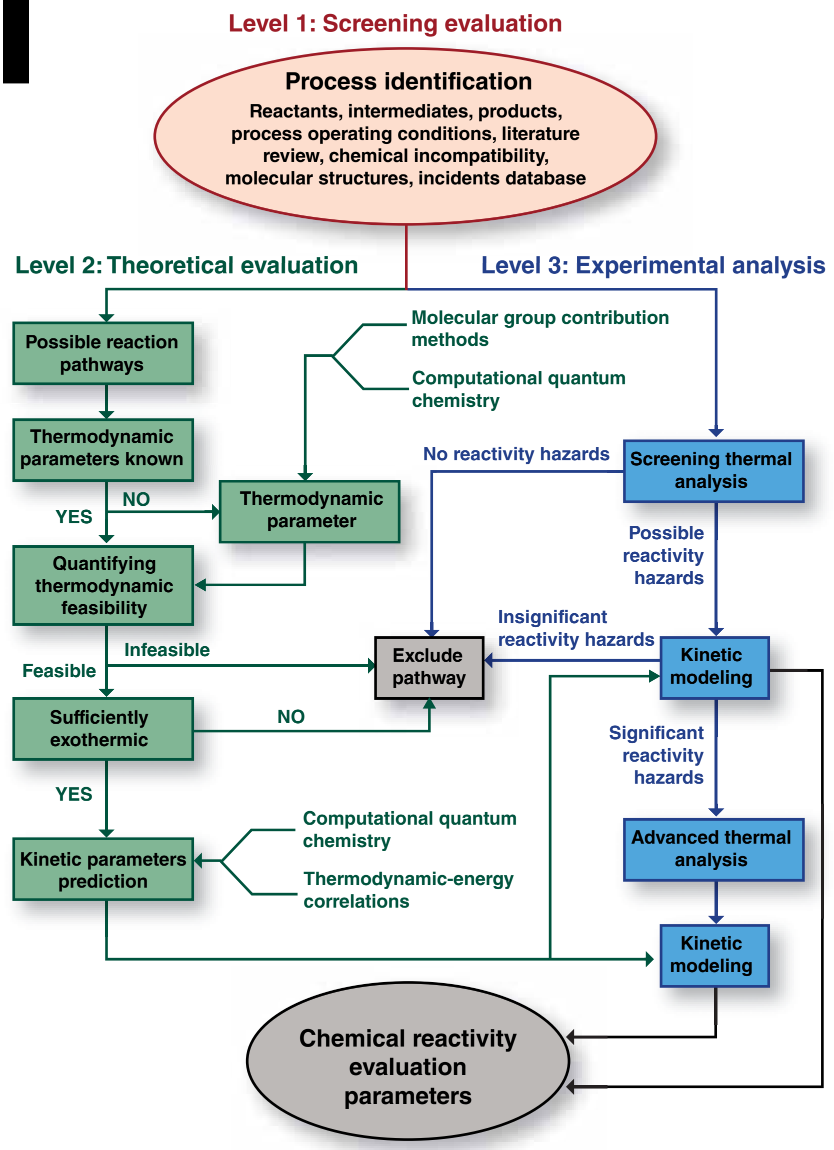

FIGURE 1. This three-level systematic approach for the evaluation of reactive chemistry can help to identify potentially hazardous behaviors, including exothermic activity [*14*]

Though many advances in terms of regulations and research have been made, reactive chemical incidents continue to occur worldwide in a number of sectors. For example, the U.S. Chemical Safety Board (CSB; Washington, D.C.; www.csb.gov) identified 167 reactive-chemical incidents from 1980 to 2001, causing 108 deaths [*2*]. An analysis performed by the French data bank ARIA (Lyon, France; www.aria.developpement-durable.gouv.fr) showed that between 2005 and 2010 in France, 352 incidents involved sites of polymer production and manufacturing of plastic materials and resins [*3*].

The high number of incidents attributed to reactivity underscores the importance of industry awareness of these chemicals. Knowledge of reactivity can help to prevent disasters and plan better hazard-mitigation techniques at CPI facilities. This article addresses the process safety concerns arising from the use of potentially reactive chemicals in the CPI. Included is a detailed look at the types of dangerous reactive chemicals found in the CPI, as well as an overview of the methods and tools used to identify and evaluate reactive hazards.

Self-reacting materials

The Globally Harmonized System (GHS) of Classification and Labelling of Chemicals [*4*] defines self-reactive substances as "thermally unstable liquids or solids liable to undergo a strongly exothermic thermal decomposition even without participation of oxygen." Different kinds of materials fall under this classification, including compounds that undergo polymerization, decomposition or rearrangement.

Polymerization. Once initiated, polymerization — the addition of smaller molecules into a large molecule via crosslinking — is generally self-sustainable and highly exothermic. Some examples of self-polymerizing compounds are acrylonitrile, 1,3-butadiene, ethylene and ethylene oxide [*5*]. At elevated temperatures, the monomers can dimerize exothermally. As the temperature increases, secondary exothermic reactions can occur, leading to potential runaway reactions, which can ultimately result in explosions. Typically, reaction inhibitors are added to the system to control the bulk temperature or pressure of the system, thereby inhibiting or slowing down the polymerization reaction.

Decomposition. The breakdown of larger chemically unstable molecules into smaller molecules is called decomposition, and can result in the release of large amounts of energy. Decomposition can occur due to mechanical input (shock-sensitive materials) or thermal input (heat-sensitive materials). Some examples of shock-sensitive materials are acetylenic compounds, acyl nitrates, alkyl nitrates, alkyl perchlorates, nitrides, *n*-halogen compounds, perchlorate salts and peroxides. Due to the explosive nature of these materials, they must be stored in cool and dry areas, and away from incompatible materials, such as flammables and corrosives [*6*]. Examples of heat-sensitive materials are those containing a peroxide component, such as butyl hydroperoxide, cumene hydroperoxide, diacetyl peroxide, dibenzoyl peroxide and di-isopropyl peroxydicarbonate, or hydroxylamine [*5*].

Special mention must be given to peroxides, since they are used extensively in the CPI. Peroxides may decompose by either shock or thermal input. The abnormal molecular and electronic structure of the molecule leads to instability in the oxygen-oxygen single bond. Because of this, the molecule tries to react and form more stable compounds. Generally, a diluent is added during the transportation of peroxides.

Rearrangement. Intermolecular rearrangement (changes to a chemical's structure) can transfer a system from a high-energy state to a low-energy state. Energy released in the process may be hazardous. Occurring frequently during isomerization reactions, examples of operations in the CPI where rearrangement is a potential risk are conversion of alicyclic hydrocarbons to aromatic hydrocarbons or conversion of straight-chain hydrocarbons to branched-chain hydrocarbons. Methylcyclopentadiene (MCP) is an example of a highly reactive, hazardous and poorly characterized compound in the CPI. It is reported that MCP is usually stored below –20°C, or in a very diluted alcoholic solution [*7*], as dimerization is measurable above 0°C and normally completes within 2–3 h at 60°C [*8*].

Reactivity with other chemicals

Certain materials may be stable by themselves, but will react in the presence of other substances, such as atmospheric oxygen or water. The universal presence of oxygen is a major hazard associated with oxygen-reactive materials, which can be classified as pyrophoric materials, flammables and combustibles and peroxide formers.

Pyrophoric materials. Chemicals that, even in very small quantities, are liable to ignite within five minutes after coming into contact with air are classified as pyrophoric materials [*4*]. The reaction (oxidation or hydrolysis) releases sufficient energy to cause ignition of the material. These materials may exist in a solid, liquid or gaseous state. Some examples of pyrophoric materials are finely divided metals, alkali metals or white phosphorus [*5*]. Closed containers with an inert environment are required to store these materials. In some cases, nonreacting liquids may also be used to immerse the material. Also, diluents may be used in some cases to reduce the concentration [*9*].

Flammable and combustible materials. Another way to classify oxygen-reactive materials is by their flammability or combustibility. A flammable solid is any solid that undergoes combustion readily or contributes to the start of fire through friction [*4*]. Generally, powdered, granular or pasty chemicals are considered to be readily combustible. The U.S. Occupational Safety and Health Admin. (OSHA; Washington, D.C.; www.osha.gov) considers liquids with a flashpoint lower than 37.8°C as flammable liquids, since the flashpoint is related to the liquid's ability to generate vapors [*10*]. Explosions can occur when flammable vapors and air are present in the right amount in an atmosphere where an ignition source is present. For gases, the explosive or flammable range is defined as the range of concentrations for which the flammable gas ignites in the presence of an ignition source. Liquids with a flashpoint greater than 37.8°C are categorized as combustibles.

Peroxide-forming compounds. Peroxide formers are compounds that slowly react with air to form organic or inorganic peroxides.

These materials will react based on the availability of atmospheric oxygen and light, as well as when left in storage over time [*11*]. As previously discussed, peroxides can be self-reacting materials — they can polymerize or cyclize to form larger compounds, which can be very dangerous. During storage, special precautions must be taken to isolate these materials from oxygen and light — monitoring over time is crucial, and suspicious inventories should be discarded. Styrene is a common example of a peroxide-forming material, and there is limited information on the thermal stability and runaway behavior of its copolymerization with other monomers, such as acrylonitrile under different monomer-feeding ratios [*12*].

Water-reactive materials. Another group of reactive chemicals are those materials that can react, potentially very violently, with water. These reactions can generate gases that are flammable or toxic, and can lead to over-pressurization of a system [*13*]. Some examples of water-reactive chemicals are calcium, fluorine, lithium, potassium, sodium and sulfuric acid. The presence of water should be completely avoided while storing and handling such chemicals.

Oxidizers. Materials (solid, liquid or gaseous) that provide a source of oxygen for combustion are called oxidizers [*13*]. They react in the presence of reducing agents and accelerate the burning rates of combustible materials [*5*]. Oxidizing agents can be grouped into three classes: relatively stable, moderately unstable and unstable [*13*]. Relatively stable materials increase the rate of burning of combustible materials and form an explosive when mixed with finely divided combustibles. Moderately unstable materials decompose vigorously, explode on heating in a sealed container and can heat a combustible material spontaneously. Unstable materials explode in the presence of a catalyst or by the application of heat, shock or friction, and liberate oxygen at room temperature.

Initial evaluation

The study of reaction hazards is imperative for engineers, as the design of reactors in the CPI involves the selection of operating conditions, including temperatures, pressures, feedrates, pressure-relief scenarios and many other parameters. Also, scaleup tests can be designed to predict larger-scale manufacturing and storage conditions for reactive chemicals.

Since reactive hazards typically vary with quantity, the evaluation of reactions or compounds usually requires various stages. First, theoretical analysis and laboratory-scale tests are often performed to assess their severity. Then, medium-scale or large-scale tests are conducted to test the reactions at conditions close to actual operating conditions. There is no universal method to evaluate reactive hazards at the laboratory scale, given that the characteristics of different types of chemicals and the requirements for the assessment vary from one chemical process to another. However, there are some general procedures that can be followed to classify the hazards. A three-level approach (Figure 1) has been proposed, where in each level, the reactive system is evaluated to understand the reaction chemistry, identify the possibility of exothermal activity and quantify the reactive chemical hazards [*14*].

Initial screening using literature and calculations can provide basic information about the properties and reactivity of the targeted chemicals. A good starting point is the U.S. Environmental Protection Agency's (EPA; Washington, D.C.; www.epa.gov) diagram-based list of questions to determine if a process requires a chemical reactivity evaluation [*15*]. Then, simple calculations for heat of reaction using values from literature, explosibility screening based on known reactive chemical groups, oxygen balances, thermochemical calculations (including average bond energy summation) and computer methods can help acquire initial estimates and guide the way for further experiments to fully understand the reactivity of the chemical [*16*]. For initial screening, OSHA recommends the use of the chemical reactivity worksheet developed by the National Oceanic and Atmospheric Admin. (NOAA; www.noaa.gov) [*17*].

Screening tests are a low-cost way to provide information about the possibility of thermal decomposition, the quantity and rate of heat release, gas evolution, autocatalysis and indication of deflagration. These tests are useful for screening a large number of samples, quick testing over a wide range of temperatures and studying the effect of different conditions and contaminants.

Calorimetry

If literature data or reliable calculation results are insufficient, it is necessary to fill the research gaps by experimental methods, many of which employ calorimetry equipment. Table 1 shows a comparison of different calorimeters [*16*].

For preliminary tests, using a temperature-scanning calorimeter can provide information via differential thermal analysis methods, such as the insulated exotherm test (IET), decomposition pressure test (DPT), closed-tube test or thermogravimetric analysis (TGA) [*16*]. The Reactive System Screening Tool (RSST, Figure 2) from Fauske & Associates, LCC (Burr Ridge, Ill.; www.fauske.com) can also be used for initial screenings [*18*].

Fauske & Associates

FIGURE 2. The Reactive System Screening Tool (RSST) can be used for a variety of tasks, such as designing emergency relief devices

TABLE 1. COMPARISON OF CALORIMETERS [*16*]

Calorimeter type	Sample size	Maximum temperature (°C)	Maximum pressure	Operation mode	Sensitivity
DSC	0.1 g	300	N/A	Temperature-scanning	1 μW
TGA	10 mg	200	1 bar	Temperature-scanning	100 μW
RSST	10 mL	400	500 psig	Temperature-scanning	0.1 °C/min
C80D	10 mL	300	350 bars	Temperature-scanning, isothermal	0.1 μW
ARC	5 mL	500	200 bars	Isothermal, heat-wait-search, heat ramp	0.04 °C/min
APTAC	500 mL	500	2,000 psig	Heat-wait-search, heat-soak-search, Isothermal, heat ramp	0.05 °C/min
VSP2	120 mL	400	130 bars	Adiabatic	0.05 °C/min
RC-1	50–5,000 mL	300	300 bars	Isothermal, isoperibolic, adiabatic	0.02 °C/min

For further accuracy, assessment of reactive chemicals is performed using adiabatic calorimeters, such as the Automatic Pressure Tracking Adiabatic Calorimeter (APTAC, Figure 3) or the accelerating-rate calorimeter (ARC, Figure 4), from Netzsch Group (Selb, Germany; www.netzsch.com).

For larger-scale and condition-dependent studies, isoperibolic calorimeters and isothermal calorimeters, such as the RC1e (Figure 5) from Mettler-Toledo (Greifensee, Switzerland; www.mt.com) or the HEL Simular [*19*] can be used.

Temperature-programmed equipment, such as a differential-scanning calorimeter (DSC) or the C80D, is widely used to detect reaction onset temperature and self-accelerating decomposition temperature. The onset temperature is the temperature where the exothermic reaction can be detected by the equipment in use. It should be noted that the onset temperature depends highly on the accuracy of the applied equipment. Therefore, different equipment may have a different onset temperature for the same reaction. DSCs can also measure heat of reaction and time to maximum rate [*20*]. TGA equipment is usually used in combination with other compositional analysis tools, including flame-ionization, infrared and mass-spectroscopy detectors, making it a powerful technique for identifying decomposition products [*16*]. It can also be combined with a DSC to detect and analyze the behaviors associated with the generation of volatile species.

The RSST is a pseudo-adiabatic calorimeter used for rapid measurement of a reaction's thermal behavior. A sample is usually heated at a constant rate, which can vary from 0.25 to 2°C per min. The calorimeter can compensate for heat losses by adding additional energy generated from an electric heater [*18, 21*]. Parameters that can be obtained from the RSST include the detection of exotherms, onset temperature, onset pressure and rate of heat or gas evolution.

An RSST can be used not only for screening reactive chemicals, but also for designing emergency relief devices in conjunction with more accurate calorimeters. This is done by modeling pressure-relief scenarios, such as loss of cooling, loss of stirring, mischarge of reagents, mass-loaded upset, batch contamination or fire-exposure heating. An RSST uses experimental data, such as the rates of temperature and pressure rise during a runaway reaction, to provide reliable energy and gas-release rates, which can be applied directly to full-scale process conditions. The knowledge generated from testing can be used in the design stages for the development of safer and more efficient processes.

The RSST can be used to study three types of reactive systems: vapor, gassy and hybrid.

FIGURE 3. Adiabatic equipment, such as the APTAC, can be used to design safer work practices in reactive systems based on the determination of thermodynamic parameters over the whole reaction process

FIGURE 4. An accelerating-rate calorimeter (ARC) maintains isothermal conditions and can be used to determine the likelihood of runaway reactions

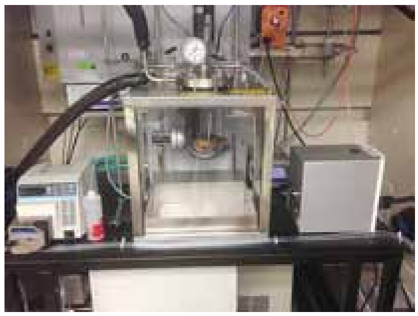

FIGURE 5. The RC1e calorimeter is suited for larger-scale and condition-dependent studies because it can accommodate very large sample sizes

A vaporizing (or tempered) system often contains components whose vapor-liquid equilibrium controls the reaction temperature and reaction rate for a fixed containment pressure. This occurs when components boil prior to the gaseous decomposition, so heat from the exothermic reactions is removed by the latent heat of vaporization, and the system pressure is equal to the component vapor pressure. The principal parameter determining the vent size is the rate of temperature at the relief set pressure.

A gassy system contains a reaction or decomposition that produces non-condensable gases, with continually increasing containment pressure and a loss of tempering, where the reaction temperature may escalate rapidly. The total pressure is controlled by the gas generation, and the vent size is determined by the maximum pressure-rise rate. It should be emphasized that a vapor system may evolve into a gassy system when the tempering is lost, which may lead to a hybrid system.

A hybrid system has both tempering and gassy characteristics, where gaseous decomposition occurs prior to boiling, but the rate of reaction (the gas produced by decomposition) is still tempered by vaporization. The total pressure in the vessel is the sum of the gas partial pressure and the vapor pressure, and both the rates of temperature and pressure rise are needed to determine the proper vent size.

Adiabatic calorimetry. Adiabatic calorimeters provide useful information on thermodynamic parameters. Adiabatic calorimetry tests can record temperature profiles over the whole reaction process. The analysis of the results includes the onset temperature, adiabatic temperature rise, self-heating rate, pressure-rise rate, time to reaction, velocity constant, activation energy and heat of reaction. Information obtained from the instruments can be used to calculate runaway reaction kinetics and conduct vent-sizing analysis. A simple test using an APTAC's venting capability can help to generate pressure-relief sizing data, by providing information about maximum temperature and pressure, rates of temperature and pressure rise and gas and vapor production within the system.

The APTAC can function in heat-wait-search mode, as well as heat-soak-search mode, to determine onset temperature and self-heating rate for reactive materials. For example, both modes have been used to study the runaway behavior of 25 wt. % hydroxylamine nitrate (HAN). A comparison of the two modes shows that HAN decomposition exhibited a strong autocatalytic behavior and that the explosion state could start at a much lower temperature following a certain aging period. Based on these experiments, it is recommended that special work practices be applied for handling HAN at low temperatures, and that longterm storage of HAN should be avoided [*22*]. The APTAC has also been used to study the effect of metal contaminants on hydroxylamine (HA), determining that the presence of metal contaminants or significantly higher temperatures can greatly increase the decomposition rate, creating hazardous conditions [*23*].

Isoperibolic calorimetry. Another form of calorimetry is isoperibolic calorimetry, which can be considered as a simple form of a heat-flow calorimetry. With this technique, the heat transfer medium is maintained at a constant temperature, and the temperature difference between the sample and the medium is recorded, providing data about heat flow. In this type of calorimetry, large amounts of sample can be used. Experiments using isoperibolic calorimetry on a 20 g solution of HA in water demonstrate that an increase in HA concentration or temperature results in a faster reaction rate. In this case, reaction conditions dramatically affect the global heat of reaction. Also, the presence of metals or gases in the environment can exacerbate the explosivity of HA [*19, 24*].

Isothermal calorimetry. The isothermal calorimeter is a kind of heat-flow calorimeter where a heat-transfer medium is applied to remove heat as it is generated, maintaining isothermal conditions within a sample in the reactor. This type of calorimeter (specifically the HEL Simular model) has been used to identify the intermediates that form during the thermal decomposition of HA, as spontaneous formation of unstable intermediates can trigger a runaway reaction [*25*].

Micro-calorimetry. For very small sample sizes, a micro-calorimeter or microreactor-based calorimeter can be used to measure enthalpy and heat capacity changes [*26*]. A microcalorimeter can measure the heat flux of a small thermal mass and reagent quantities at the nano-scale. In solutions, heat flux into or out of the sample usually occurs during reactions. This process involves an interaction between two molecules, the conformation of macromolecules or the shifts in structure of multimolecular colloidal systems [*16*]. The advantage of a micro-calorimeter is that it can provide uniform heating and cooling while achieving a high level of temperature homogeneity, thus enhancing thermal sensitivity and improving analysis capability. It is also inexpensive and portable.

Process design example

There are many ways in which calorimeters can be used to design inherently safer processes. For example, an important reaction in the pharmaceutical industry, the *n*-oxidation of alkyl pyridines, uses an excess amount of hydrogen peroxide in the presence of phosphotungstic acid as a catalyst. Hydrogen peroxide shows condition-dependent decomposition and has the potential to lead to a runaway reaction, resulting in the generation of oxygen, which presents further explosion hazards. To achieve conditions where the undesired decomposition of hydrogen peroxide can be minimized, the APTAC has been used to determine the runaway behavior of the reactants and the products to ensure that altering process conditions will not compromise the safety of the process or affect the quality of reactants or products. Subsequently, other calorimeters were used, including, the HEL Simular and the RC1, to validate and complement previous studies arguing that an increase in catalyst quantity and temperature can potentially eliminate the decomposition of hydrogen peroxide, thus favoring the selectivity toward the *n*-oxidation. This work also allowed an assessment of additional factors, such as feed and stirring rate, and determined the most dominant ones, allowing for the development of design recommendations for an inherently safer system for this reaction [*27*].

The main objective of laboratory-scale study is to obtain information pertinent to operation at plant scale. To carry out an exothermic batch or semi-batch reaction under thermal control is to remove the heat of reaction at the same rate as it is generated. The rate of heat generated depends on reaction temperature, reactor configuration (batch or semi-batch), reactant accumulation and the occurrence of thermal events, such as precipitation decomposition, gas evolution and phase change. The experimental techniques should be able to do the following: simulate full-scale reactant addition rates, batch temperature and time profiles and processing conditions; include any other sources of heat or heat loss, such as energy input from the stirrer, heat loss from a condenser; account for changes in physical properties, such as viscosity or specific heat, during the reaction; and account for changes in heat transfer through the reactor wall. The calorimetric techniques described in this article can be used to design and scale up any chemical reaction.

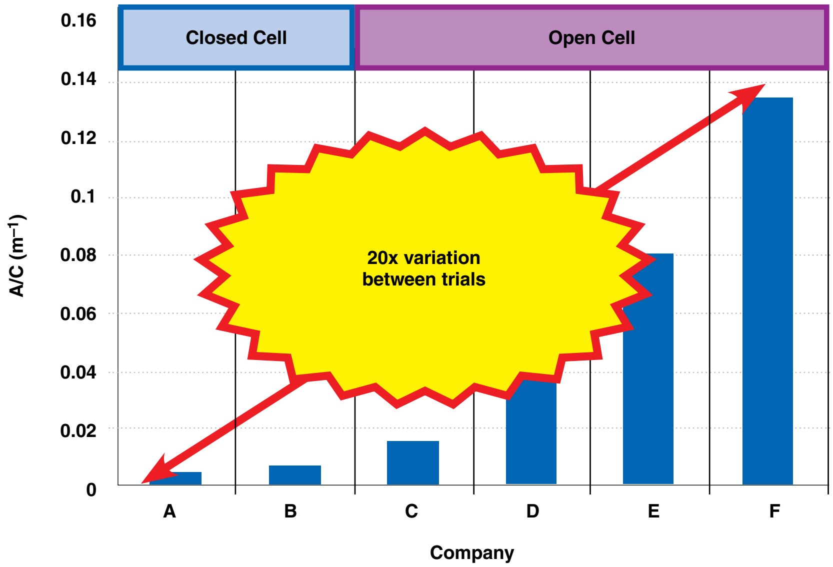

FIGURE 6. The results of the round robin vent-sizing exercise show great variation in results among the participating parties, due to differences in equipment configuration and calculation assumptions applied, among other factors

Performance gaps

Calorimeters used for obtaining reactivity data have limitations and present some gaps. For instance, instrument sensitivity, sample size and operating mode can play an important role in the detection of parameters like onset temperature, which can potentially result in differing results being obtained for the same chemical [*28*]. An example of this has been presented in Ref. 12, where RSST and APTAC measurements were performed on seven styrene-acrylonitrile monomer-feeding ratios and the resulting onset temperatures were quite different — the RSST result was around 106°C, while the APTAC gave a result of 91°C. This large difference is due to the greater heat losses seen in the RSST cell when compared with the APTAC, which experiences much more near-adiabatic behavior and therefore provides more accurate predictions. The APTAC also provides more details on secondary temperature activity, which the RSST cannot capture.

In another example, the discrepancies in experimental evaluations of reactive properties of dicumyl peroxide (DCP) are illustrated by the round robin test proposed by the Health and Safety Laboratory (Buxton, U.K.; www.hsl.gov.uk) [*29*]. In this test, seven organizations, including research centers, universities and consultancy companies, were asked to use an adiabatic testing method to size a vent area to protect a reactor containing a solution of 40% DCP in 2,2,4-trimethyl-1,3-pentanediol di-isobutyrate exposed to fire. As observed in Figure 6, the calculated vent area differed greatly — a factor of 20 separated the minimum and maximum estimates, due mainly to the different equipment, configurations and assumptions used.

Moreover, inconsistency among various calorimeter testing procedures results in insufficient experimental data. The lack of available experimental data can be attributed in part to a reluctance to share results, for reasons including liability and confidentiality concerns, as well as a need for interpretation of reactivity data by subject-matter experts. Consequently, there is no current mechanism for industry-wide sharing of reactive chemistry data [*2*]. Concerning these gaps in experimental determination of chemical reactivity, future research is needed on the design of calorimeters and the experimental methods applied to reduce the range of experimental results obtained.

Looking ahead

In addition to the gaps in calorimetry performance, the absence of a systematic procedure to scale up experimental results also hinders chemical reactivity determinations — the ability to evaluate the hazards of larger sample sizes is crucial, since the scale can have a significant effect on the hazards. Finally, chemical reactivity assessment can also be more systematically applied during the design phase of a process, especially to determine an inherently safer design.

Generally, eliminating further incidents in facilities with reactive chemical hazards requires industry, academia and government to work together to improve communication and information sharing, and to provide guidance and quality training. As explained previously, there is no system for sharing reactivity data, which would allow for the development of more efficient preliminary screening tests.

There is also no standard procedure for evaluating chemical reaction hazards [*30*], and guidelines or clear procedures are needed. The systematic approach shown in Figure 1 presents a multilevel approach, but also indicates the importance of choice of the method depending on what needs to be predicted: dominant pathways or accurate thermodynamics. A 2006 study surveyed the chemical engineering departments of various U.S. universities — only 11.2% of responders had a compulsory core course in process safety offered to undergraduates [*31*]. Since then, the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology (ABET; Baltimore, Md.; www.abet.org) has stated that "curriculum must include the engineering application of the basic sciences to the design, analysis and control of chemical, physical and/or biological processes, including the hazards associated with these processes." [*32*] ABET's declaration is a major step toward a more systematic education in process safety, and will certainly result in a more comprehensive understanding of reactive chemicals in the CPI. ■

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The Next Step Change in Process Safety

Leveraging the convergence of operational and information technologies can aid in minimizing risk

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From plastics and synthetics to fertilizers and fuel, the general public takes for granted so much of what the chemical process industries (CPI) produces, and the risks associated with CPI production facilities are not typically considered. That is, until the next headline-creating industrial catastrophe occurs. The human toll of such disasters plays out across ruined lives, devastated communities and obliterated opportunities. The effects can stretch out for years in the form of chronic health conditions, diminished earning capacities and contaminated environments.

However, those connected to the CPI do not forget the risks, nor can they afford to. Catastrophic incidents, large and small, have increased the focus on process safety management in production facilities around the world. Although enormous progress has been made in preventing them, incidents continue to occur. In fact, while safety incidents have been declining in number since 2008, those that do happen have been increasing in severity, according to the American Institute of Chemical Engineers (AIChE; www.aiche.org).

Today, the industry is on a cusp, seeking the next breakthrough improvement in process safety management — one that can empower facility operators by notifying them when risk increases, and enabling them to respond before abnormal operation escalates uncontrollably and causes injuries, monetary loss or environmental damage. This article examines how key elements, such as automation and information-management systems, as well as operating discipline, can begin to converge to make this proactive approach a reality.

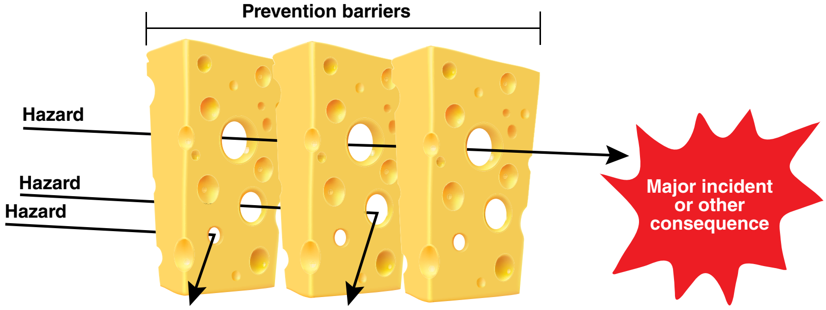

FIGURE 1. The "Swiss Cheese" model involves the implementation of various safeguards and barriers to prevent the propagation of a hazardous situation — however, gaps exist in this setup and must be addressed

Cascading causes of incidents

Numerous studies and analyses have concluded that the majority of safety incidents result from human error. Operating discipline is typically at fault, since these errors spring primarily from defects and deficiencies in following operating or maintenance procedures, and in applying necessary administrative controls to ensure competency, effective communications, performance measurement and change management. For example, work instructions that are incomplete, inaccessible or illegible lead to inconsistent execution of procedures; poor communication causes insufficient worker-to-worker handoffs; stress and excessive fatigue impair decision-making and contribute to procedural missteps; and poor human-machine interfacing can lead to operator confusion and delayed responses.

Many companies minimize the contribution of human error in incident initiation through the implementation of safeguards or barriers based on the so-called "Swiss Cheese" model of accident causation used in risk management (Figure 1). The purpose of this model is to reduce the likelihood of an incident occurring, or to reduce the impact if an incident does occur. However, once these safeguards and barriers are introduced into operations, rigorous procedural controls are then necessary to ensure their integrity. Otherwise, inevitable human errors and equipment degradation reduce the effectiveness of the model.

Shifting tasks from manual to automated operation reduces the potential for direct human errors in initiating an incident, but in order for the automated functions to be effective, asset-integrity systems covering the operation and maintenance of these safety-critical pieces of equipment become necessary. Whether manual or automated, a consistent and accurate execution of safety-critical tasks requires operating discipline and the ability to monitor for changes in risk. Incident investigations reveal that deterioration of the barriers and safeguards often start long before the accident occurs, and that no systems existed to detect and report their loss. There are three main contributors to this deterioration of barriers and safeguards: the passage of time, covert risks and complacency.

The passing of time. Just because a safety incident has not occurred for some time does not mean that all is well. If assets are poorly maintained and operating processes not regularly checked for safety effectiveness, they will eventually stop providing the level of risk reduction they were originally designed to provide.

Covert risk. Risk has a propensity to emerge from the least-expected places. The inability to visualize where the risks are and the source of the next incident is an open door to disaster.

Complacency. Statements like "This is how we always do it" and "Don't fix it if it isn't broken" are heard frequently. As months and years pass without incidents, it is all too easy to become complacent, especially when it is not readily apparent where hazards can stealthily develop. That is when poor habits can infiltrate processes, and running overtime becomes the new normal.

Overall, the "Swiss Cheese" model alone is too porous and static to achieve the next safety performance breakthrough. Instead, the confluence of human error, operating data and information-management systems must be addressed. Process-safety challenges must be viewed as a holistic system-integration problem in order to make meaningful progress.

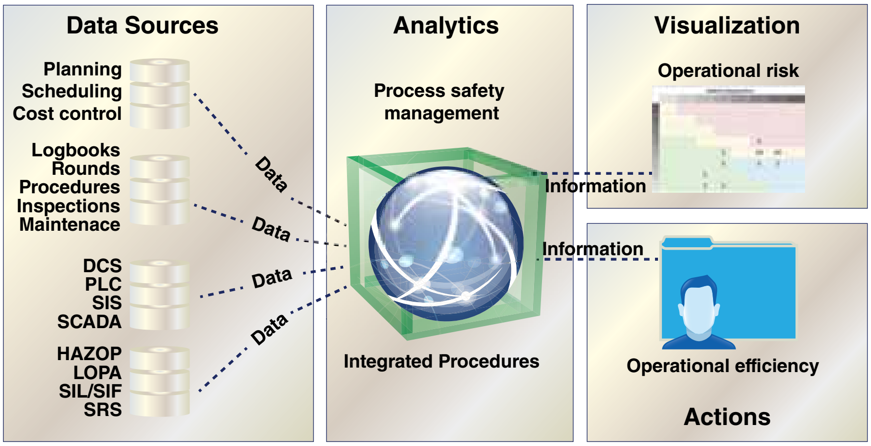

FIGURE 2. Various sources of information can come together to provide a realtime visualization of operational risks

Holistic systems integration

Non-integrated process-safety programs may address some of the "low hanging fruit," but they do not prevent everything, as is evident from the prevalence of catastrophic incidents. The integration of manual tasks with automated procedures and smart interface design aids in avoiding deficiencies in procedure implementation and communication, as well as minimizing the potential for human error. The key pieces already exist in the operational-technology (OT) and information-technology (IT) realms and now must be pulled into conjunction to comprehensively address the growing complexity of the human factors that contribute to safety incidents.

For example, on the operational technology side, companies can implement state-based unit-control schemas to address a range of normal and abnormal operating conditions. They can also employ automation systems to detect abnormal events and take preemptive actions to stop incident propagation. Additionally, they can implement abnormal situation management (ASM) graphical standards to optimize operator navigation during abnormal events and alarm management to promptly focus attention on safety-critical issues.

On the IT side, companies can integrate standard operating procedures (SOPs) with automated delivery of the latest revision of the required tasks, electronic time-stamped signatures, prescribed records and quality tolerances. Any procedure can be further supported with safety rules and automated interlocking functions, to ensure that manual tasks are sequenced properly, that the proper individuals are notified for certain tasks, and that detailed findings are consistently recorded for monitoring purposes. Further, workflow applications can be deployed to aggregate the results to the desired level of granularity to facilitate adequate information sharing and reduce the chances of human error.

Most promising of all is the opportunity to integrate realtime analysis into the overall picture to identify operational risk before it translates into incidents, and to drive the most effective risk-mitigation schemes. Figure 2 illustrates how data can be leveraged through proper integrated procedures to help visualize risk.

Static versus dynamic risk

Risk is not static; things are always changing. Safeguards can develop faults, or they can be down for maintenance. New and different activities may be taking place during installations. Organizations, people, resources and logistics can easily and quickly shift. In short, nothing should be taken for granted. Rather, organizations must bolster safeguards and barriers in a dynamic fashion. To do this, they can monitor leading indicators of increased vulnerability to incidents on a day-

FIGURE 3. Cumulative risk is shown for an entire operating unit, drawing attention to all areas that are prone to incident-causing situations

to-day basis. A daily review of cumulative risk enables organizations to digest new operations information. Where are breaks in the plan that will defer planned work? What defective equipment has been found that cannot be repaired immediately? Which employee is unexpectedly off the job today? The accumulated information can be used to fuel risk assessments, both operational and safety-critical, leading to decisions on whether to shut down or to take compensating measures.

While this provides a reliable basis for operational decision-making and control, and ensures that levels of cumulative risk remain tolerable, the key step is to leverage the convergence of OT and IT and react ahead of incidents through realtime risk monitoring, analysis and advising. Figure 3 shows a visualized representation of cumulative risk for an operating unit.

Proactive analysis

Traditional approaches to process safety management have leaned heavily on post-mortem analysis, investigating what went wrong and lessons to be learned. Although analysis after the fact is useful, organizations must start asking "How can we be more proactive in addressing operational risk?" in order to truly slow the pace of incident occurrence and decrease incidents' severity. The answer lies in the integration of operational and information technologies.

The clearest way to be more proactive is to integrate a production facility's wealth of realtime operational data, such as instrumentation and control data, with technology for dynamic risk analysis. When done comprehensively, this can result in a realtime dynamic risk advisory capacity for monitoring and immediately alerting personnel to risks as they change and develop, and for providing an optimal course of action to maintain the integrity of the facility.

Accessing and amalgamating all of the required data is challenging, because data can reside everywhere: from operations, maintenance and automation systems, log books, operator rounds, mechanical inspections, lock-out or tag-out applications and databases. Additionally, information is being created and changed constantly. Data needs to be accessed from disparate systems, validated, transformed, integrated and contextualized in order for it to drive actionable intelligence. Technologies do exist to complete the heavy-lifting integration tasks. Thus, analytics applications can then connect the dots, comparing asset operation and maintenance performance against a safety basis, and alerting personnel to any deviations.

Further, the proactive interface can be strengthened even more through the use of visualization technologies in addition to analytics. Analytic technology can calculate the change in risk dynamically, (for instance, weighing the consequences of an uncompleted operator round or a non-implemented proof test on a critical device) and update a facility's risk matrix in realtime with the revised impact. Visualization technology can then help focus employees' attention on the change in risk using geospatial representation and color-coded graphics (Figure 4) for impacted facilities, units and equipment.

Putting intelligence into action

The next step is to automatically direct appropriate corrective actions based on this realtime intelligence. In an example scenario, an operator scans a screen that maps an entire facility and displays the dynamic risk levels associated with each of the facility's unit operations at that moment. A specific unit displays an elevated level risk and the operator investigates to discover a deviation from the design specification that is now raising the likelihood of an inci-

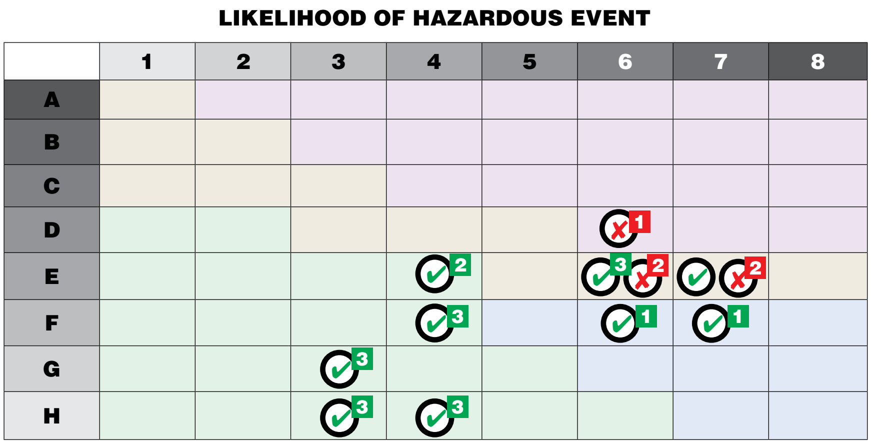

FIGURE 4. The capability to visually classify all the various risks for a facility allows for quick responses by personnel

dent, and perhaps one of higher severity, than was originally planned into the design of the unit. In effect, the operator is viewing a window of a unit's behavior "as operating" versus "as designed."

Examining further, the operator consults a safety rulebook to identify the cause of the increasing risk and to see what tasks are necessary to resolve the problem, ensure continued safe operation and restore operational integrity. The operator can then schedule those tasks appropriately, and monitor their completion, while taking the production unit or some of its equipment offline if required by procedure.

Multilevel utilization of data

The same collected operational data, along with its attendant data-integration infrastructure, that drives realtime analytics and improved situational awareness can also be leveraged in other ways to increase operational risk awareness, power predictive insights and enable proactivity.

By definition, realtime data have a limited shelf life and quickly become historical data. As today's realtime data become tomorrow's historical data, they can be compiled to inform periodic critical reviews with asset managers and technical authorities, monthly governance reviews with asset leadership teams and quarterly reporting to executive committees. Engineers are able to analyze the accumulated data to enhance designs and processes, while managers and executives can utilize the data to improve process safety and enterprise asset-management strategies. Meanwhile, analyzing realtime data in conjunction with historical data can help organizations more effectively identify and track trends, not just within one facility but across many, and help drive successful preemptive actions.

However, time-based information alone is not enough to present a complete picture of operational risk. The attendant data-integration infrastructure mentioned above is required to provide the context (for example, the unit processing state) in which the data are collected and presented. This context is a necessity for comparing best-practice historical data with realtime operational performance. Within this process-state context, events (planned or abnormal) can be collated, analyzed and acted upon quickly.

Procedural, state-based process-control standards, such as ISA 106, have been established to provide the appropriate data context and process-control vehicle for realtime event mitigation of an abnormal situation. Without providing such context keys, it is very difficult to provide the multilevel datasets required to enable the analytics engine to work. However, with state-based process automation standards in place, basic process control is fully integrated with safety shutdown systems, providing a key piece of enablement technology for rapid, closed-loop response to an abnormal situation. State-based control strategies also provide the event context to continuous, streaming information, which is vital to analysis and reporting.

Overall, interactions with integrated data, aggregated at the appropriate level, improves the ability to benchmark performance, plan alternative courses of action and mitigate abnormal situations effectively. Figure 5 illustrates some ways that aggregated data can be used to schedule reviews and discussions about safety-critical tasks.

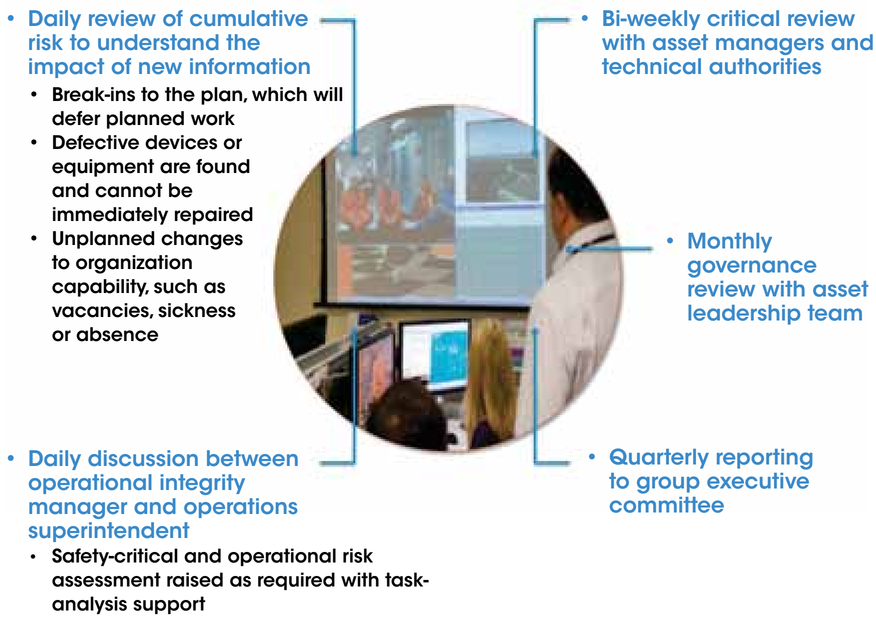

FIGURE 5. Day-to-day information aggregation can help in scheduling periodic reviews regarding process safety and asset management

Employing cloud and mobile

The previously discussed emerging paradigm for process safety management is proactive and driven by data from a myriad of sources. Now, it is time to discuss how to best deliver the data to the appropriate location, using three technologies that have proven to be game-changing in many industries: mobile (display), cloud (database) and industrial Ethernet (IE) communications.

Mobile technology has been problematic from a control standpoint for the CPI. There is a natural propensity for individuals to use mobile technologies to "move things along" outside of normal workflows. Sometimes this works to great effect; sometimes it does not. Nonetheless, there is no arguing the value that the correct application of mobile technology can have in maximizing asset health and process safety.

Areas where mobile is particularly valuable include field-data capture, event logging, operator rounds, safety inspections and audits and communicating operations and maintenance instructions, among others. The larger the facility, and the more dispersed the resources and assets are, the more valuable mobile capabilities become. Mobile technology is also economical, eliminates paperwork, enhances compliance and — because it is so pervasive in everyday life — the learning curve is far from steep.

The advantages of cloud deployments are clear as well. Cloud-based process-safety management enables organizations to quickly roll out new process-safety capabilities, and can enhance collaboration between individuals and departments. The cloud can also reduce the costs of accessing and integrating data, help eliminate information silos and enable cost-effective enterprise-wide visibility. Importantly, the cloud is also pivotal for transferring data in a controlled and secure fashion.

Another key enabler is IE. Supported by wireless-mesh networking and secure communications protocols, IE enables a flexible, responsive, end-to-end networking architecture that provides connectivity, collaboration and integration. As a result, data can be delivered from the shop floor to the cloud, and then from the cloud to a mobile device efficiently and securely.

Operational integrity windows

The new imperative for CPI companies is knowing with certainty the source of the next incident, and being able to avoid it or at least minimize its effects. Regulatory agencies, shareholders and employees demand this. Doing this will require the ability to:

- Reduce operational risk by unlocking data for realtime insights and enterprise-level visibility
- Examine the "big picture" through enterprise-level benchmarking and trend analyses to guide safety strategies and keep incidents at bay
- Trust the data by leveraging validation, whether it is mobile data, or data created automatically by instrumentation and systems
- Receive instantaneous alerts on developing issues through visualization and alarm or alert technologies on top of realtime analytic applications
- Use mobile and cloud technologies to deploy and access data from the point of work or the process edge
- Implement realtime detection and automated response to abnormal conditions, be they partial process impairment or emergency shutdown events
- Have a single window into operational integrity powered by dynamic risk analysis and leveraging existing risk data, automation systems, maintenance and operations procedures and business systems for planning, scheduling and cost control

When all these abilities fall into place, a company can capitalize in new ways on existing infrastructure

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and benefit from a breakthrough in process safety performance. A process-safety paradigm shift is achieved through integration of realtime information, best operating practices and closed-loop control. Mobile procedure assistants can help avoid human error. However, in today's complex processes, human response time may not be quick enough. This is where preprogrammed safety systems provide the final layer of protection to return a process to a safe state.

Unfortunately, safety systems are conservatively designed to fail safe. In some cases, this mode of action may be premature, resulting in false process trips, causing undesirable loss of productivity. Advances in state-based control can respond in advance of the last line of defense and address the abnormal event, when it is less than critical, before shutting down the entire process. This example of "man-machine-method" integration provides the optimum response to ensure high levels of both safety and productivity.■

Edited by Mary Page Bailey

PNEUMATIC CONVEYING: Optimal System Design, Operation and Control

Numerous strategies and options for both dilute- and dense-phase conveying systems are presented here

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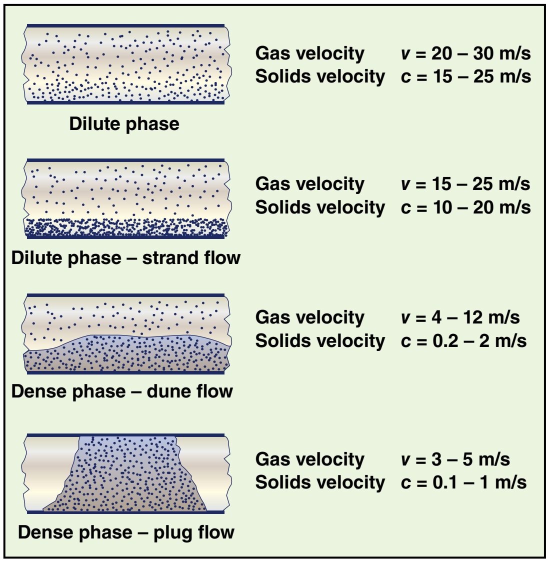


FIGURE 1. The common modes of pneumatic conveying, and corresponding characteristic data for polymer pellets, are shown here. This figure illustrates the relationship between conveying mode, gas velocity and particle velocity

Pneumatic conveying is a ubiquitous mode of conveying bulk solids in a wide range of industries, including chemicals, plastics, grain, food, agricultural, mining, power and cement. In recent years, the capacities, distances and variety of materials to be conveyed have increased, often approaching the design limitations of the available hardware. In addition, energy-efficiency considerations require designing pneumatic conveying systems closer to the theoretical limit. Meanwhile, the operational reliability and stability of dense-phase systems have been significantly enhanced through the application of sophisticated air-control systems. This article outlines some of the underlying concepts for optimal design and operation of both dilute- and dense-phase pneumatic conveying systems.

Introduction

Pneumatic conveying systems have been used for more than a hundred years to convey bulk solids in closed piping systems, using air or other gases to move solid particles through the conveying line. Early systems operated in dilute-phase mode, where the individual particles were conveyed through the pipe by air that had a velocity significantly above the settling velocity of the particles being conveyed. The drag on the individual particle provided the driving force for conveyance. Historically, the conveying air was supplied by low-pressure fans. Thus, early conveying efforts were limited to relatively low pressures and low solids-to-air ratios. Increasing the solids-to-air ratio resulted in unstable conveying and eventual plugging of the conveying systems. Over time, the introduction of rotary-lobe blowers and screw compressors helped to expand the operating window of dilute-phase conveying systems, making them popular throughout the chemical process industries (CPI).

Technical advances in air-mover technology and high-pressure feeding devices helped to support the development and successful application of dense-phase pneumatic conveying. Much higher solids-to-air ratios could be achieved at much lower velocities, thereby generating significantly reduced wear on the line and less particle attrition.

Various modes of pneumatic conveying of polymer pellets and associated operating variables are shown in Figure 1. The flow patterns and associated characteristic data are material-specific, and data must be determined in laboratory facilities, test plants or full-size industrial installations.

Pneumatic conveying systems have a number of features that differentiate them from mechanical conveying systems. Pneumatic conveying systems are advantaged due to their flexibility in routing, compactness and ease of installation, containment during conveying (which protects material from environment and vice versa), and they have the ability to handle multiple products with minimal cross-contamination. The drawbacks, however, include higher energy consumption and the potential for greater attrition and wear compared to mechanical systems.

Over the past few decades, advances in calculation procedures based on physical models, coupled with better hardware, such as air movers, feeders and control systems, have helped to expand the range and scale of applications. Today, the largest pneumatic conveying capacities have been achieved for cement, flyash, alumina and terephthalic acid. All of these bulk solids can now be conveyed at rates in excess of 100 ton/h and conveying distances longer than 1,000 m.

The relationship between flow pattern (mode of conveying) and key operating variables (such as pressure drop, gas velocity and solids flowrate) for a given conveying layout is best represented by the system state diagram (Figure 2; often referred to as the Zenz plot). An alternate approach for the state diagram — one that plots the gas flux versus solids flux with lines of constant conveying pressure — has also been used by some researchers. In the original Zenz plot, the pressure drop across a section (horizontal or vertical), was plotted against superficial gas velocity on a log-log scale. Extending this approach to represent the entire conveying system, today the overall pressure drop is typically plotted against terminal gas velocity on a linear scale.

For blower selection, where air flowrate must be specified, the use of gas flowrate on the abscissa (x-axis) comes in handy. In any pneumatic conveying system, each combination of bulk material characteristics and specific pipe-routing schematic will have its own unique conveying characteristics, hence a system-specific state diagram. Such a diagram for any given conveying system will also depend on conveying length and routing configuration, since the overall pressure drop is used for the ordinate (y-axis). This diagram is, however, independent of the feeding technology (for instance, whether a blow tank or rotary valve is used).

In the system state diagram (Figure 2), the lowest curve represents the pressure drop characteristics of single-phase (gas) flow in a conveying line. Here, the pressure drop is proportional to the square of gas velocity. When solids are introduced into the conveying line, additional energy is required to overcome losses due to friction, wall impacts, and to initially accelerate the particles and then reaccelerate them after bends or vertical lifts. These losses manifest themselves as additional pressure drop, which increases with increasing solids flowrate. If the conveying gas velocity is sufficiently high, then stable dilute-phase conveying conditions will prevail, where all particles are fully suspended in the conveying gas (Figure 1, top).

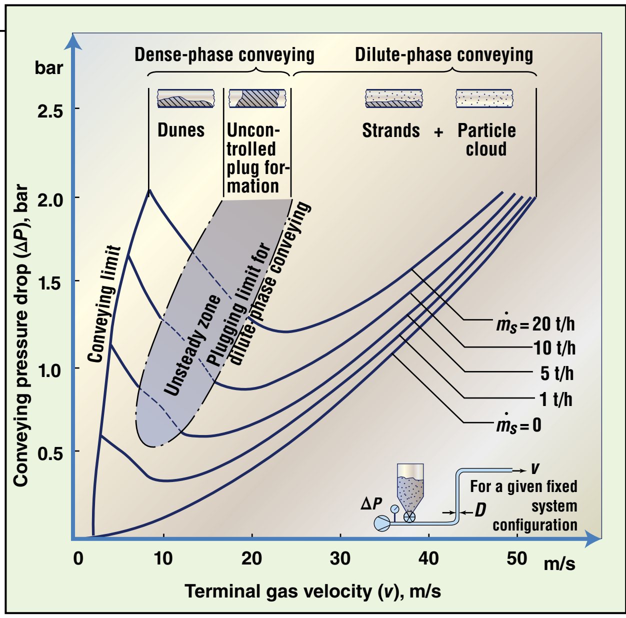


FIGURE 2. The state diagram of pneumatic conveying shows the relationship between key operating variables (such as conveying rate, gas velocity and pressure drop), and provides demarcation of corresponding pneumatic conveying modes

As the gas velocity (or gas flowrate) is reduced, the pressure drop continues to decrease, even though solids flowrate remains constant. Correspondingly, the flow pattern in the conveying line changes from fully suspended flow to stratified flow with a higher concentration of particles in the lower section of the pipe. Eventually, the particles begin to fall out of suspension and begin to roll, slide and move along the bottom of the pipe. The gas velocity corresponding to this state of flow is called the saltation velocity, and the corresponding pressure drop shows a minimum in the characteristic curve. Operating conditions to the left of the pressure drop minimum will result in additional settling of particles (saltation), which leads to sluggish conveying behavior and may cause temporary plugging of the conveying line along with intense line vibrations.

This unstable zone (shown in Figure 2) separates the dilute-phase from the dense-phase areas in the state diagram. If the conveying pressure required for stable conditions exceeds the available pressure from the blower, compressor or compressed plant air supply, then the conveying system will stall or plug.

With further decreasing gas velocity, the zone of stable dense-phase conveying is reached — to the left of the unstable zone (that is, at lower gas velocities but significantly higher pressures). The conditions that produce stable, dense-phase conveying are much more limited compared to those that produce dilute-phase conveying.

Finally, the line shown furthest to the left in Figure 2 represents the termination of dense-phase conveying in the form of a stationary plug. The zone of stable, dense-phase conveying is wedged between the unstable region and the conveying limit. The pressure required to move a slug of solids is significantly higher than that required for dilute-phase conveying at the same conveying rate — thus, most practical applications require the use of compressors.

Dense-phase conveying is often referred to as "slow-motion conveying." Not all high-pressure conveying systems will actually operate in dense-phase mode or in slow-motion conveying. One must pay particular attention to the system design, line stepping (that is, increasing the line diameter along the conveying length to reduce local gas velocity) and velocity profile, and manage the conveying gas, to achieve dense-phase conveying.

Conveying characteristics may be approximated for preliminary evaluations by comparison with materials that have "similar" conveying behavior. For example, the

FEM 2581 and FEM 2481 guidelines [*4, 5*] provide guidance for how to select a reference material from a database when no actual conveying test data are available.

Material classification

Most materials can be conveyed in dilute phase as long as sufficient gas flow is available and the pipe diameter exceeds 5–10 times the maximum particle size. The potential implications of system wear, attrition and hardware must be dealt with separately.

However, not all bulk solids are amenable to dense-phase conveying mode. Whether a bulk material can be reliably conveyed in dense-phase mode will depend on its permeability and air retention (or deaeration) characteristics. Particle size, shape, particle size distribution, inter-particle friction, particle-wall friction and bulk compressibility also affect the formation, stability and movement of plugs in the line.

Bulk materials can be broadly grouped into three classes, namely:

Class I: High permeability, low air retention — with natural slugging ability. Free-flowing coarse materials with a narrow size distribution, such as plastic pellets, coffee beans and corn kernels, will have high permeability and low air retention, and therefore will naturally form slugs in dense-phase mode. Slugs of sufficiently permeable bulk solids are pushed through the conveying line by the pressure drop of the conveying gas percolating through the slugs; this also provides the energy to overcome friction between the particles and the pipe surface.

During the initial line-filling phase, due to the drag force of conveying air, the slug formed at the feed point is moved further downstream — where it may come to a temporary halt. Thus, the motion of the slug is not like a "sausage or plug" — rather, the front of the slug continuously picks up material from the stationary layer at the bottom of the pipe while the back end deposits some material to the stationary layer. At steady-state conditions, there is a continuous exchange of material between the stationary layer and the passing slug, and thus, any given slug does not consist of the same particles throughout its journey through the conveying line. Also, the packing density of the slug is reduced by the gas percolating through the solids and the solids within the slug are in a dilated (not necessarily fluidized) state. Thus, the individual particles do not transfer radial stresses like in a packed column or silo, even though the dilated slug may fill the pipe's entire cross-section.

Class II: Low-permeability cohesive powders. Powders that are fine or cohesive (or in some cases both) do not naturally form individual slugs due to their low permeability. Some common examples of such materials include beaded carbon black, fine coal, silica, TiO_2 and glass fibers. The plugs can be created initially at the feed point by alternating air injection and solids feed at the outlet of a blow tank, and by additional gas injection throughout the length of the conveying line. This additional (secondary) air injection helps to maintain a minimum state of aeration that keeps the artificially formed slugs separate and prevent excessively long slugs in the line.

Class III: Low permeability, high air retention. The third group of solids exhibits high gas retention and slow deaeration behavior. Examples include flyash, calcium stearate, fumed silica, cement or terephthalic acid. These materials are ideal candidates for being conveyed in a fluidized state. Such materials can be conveyed over long distances and at high solids loadings. The corresponding flow regime for this mode of conveying could sometimes be to the right of the pressure minimum, or in the vicinity of the pressure drop minimum, in the state diagram. The conveying distance will be limited by loss of turbulence along the conveying line. Turbulence is needed to prevent the formation of stagnant layers at the bottom of the conveying line. Various design concepts are available to generate turbulence or to maintain an aerated state for longer durations along the conveying length.

Conveying limits

The stability of dilute-phase pneumatic conveying systems depends on the ability of the air mover to deliver the necessary air volume to prevent saltation at the required operating pressures. Saltation is defined as the condition where the particles are no longer suspended by the gas stream, but begin to fall out of the suspension (either as a moving strand or layer at the bottom of the pipe). The conveying limits with respect to gas velocities for dilute- and dense-phase systems are bounded as follows:

Dilute-phase conveying:

Lower limit: The conveying gas velocity must exceed saltation conditions at the pickup location, after a bend or at a stepping location.

Upper limit: This limit is defined by system wear, product degradation and energy efficiency.

Dense-phase conveying:

Lower limit: The conveying gas velocity must exceed the plugging limit (the minimum velocity required to maintain aeration in a plug and to overcome friction to move it).

Upper limit: The conveying velocity may not reach the unsteady zone between the dilute- and dense-phase regimes.

Pressure and velocity profile

Physics dictates that the absolute pressure at the feed point is always higher than at the discharge end, regardless of the type of conveying system (pressure or vacuum) or mode of conveying (dense or dilute). As the pressure decreases, the corresponding gas volume increases — as per the Gas Law. If the line bore (diameter) is constant, then the corresponding gas velocity will consequently increase from the feed point to the discharge.

Referring back to the discussion on the state diagram (Figure 2), the flow pattern or conveying mode can change from dense-phase through unstable mode to dilute-phase as the local superficial gas velocity increases along the conveying line. As shown in Figure 3, the conveying mode changes along the conveying line due to differences in local gas velocity while the solids-loading ratio remains constant. Solids-loading ratio, therefore, is not a reliable indicator of conveying mode.

The use of secondary air injection is one way to maintain a stable mode of dense-phase conveying for Class II bulk solids. It should be noted that addition of secondary air injection results in an increase in gas and material velocity along with a decrease in solids loading along the conveying line. Depending on the conveying characteristics, the secondary air-injection points can be of discrete (single point) or continuous (longitudinal air injection) design. Preferably, the air injection should only be activated "on demand" — that is, when required due to build-up of a plug that is too long or too dense.

Constant or uncontrolled secondary air injection leads to a continuous increase in gas flow and thus gas velocity, with the potential of changing conveying mode from dense-phase into dilute-phase conveying. The maximum length of the slugs is determined by the distance between the injection points. These secondary air-injection points also serve to disintegrate long slugs into smaller ones, and this is required for stable operation of dense-phase systems with Class II materials. This mode of air injection allows the dense-phase conveying systems to operate reliably even in the unsteady zone between dense- and dilute-phase conveying.

In order to keep the velocity of the conveying gas in a desirable range (for each mode of conveying), the conveying line may need to be stepped to increasing line diameters along the conveying length (Figure 4). Upon stepping the conveying line, the gas velocity will drop back into the desirable limits at each point where the conveying pipe is transitioned to a larger diameter. The proper location for these transitions must be carefully determined to maintain the desired velocity profile.

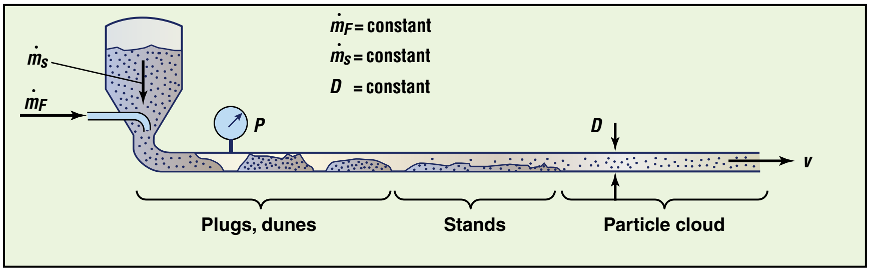


FIGURE 3. Shown here is the typical change of conveying mode along a conveying line with a constant diameter. This is a result of progressive expansion of the conveying gas

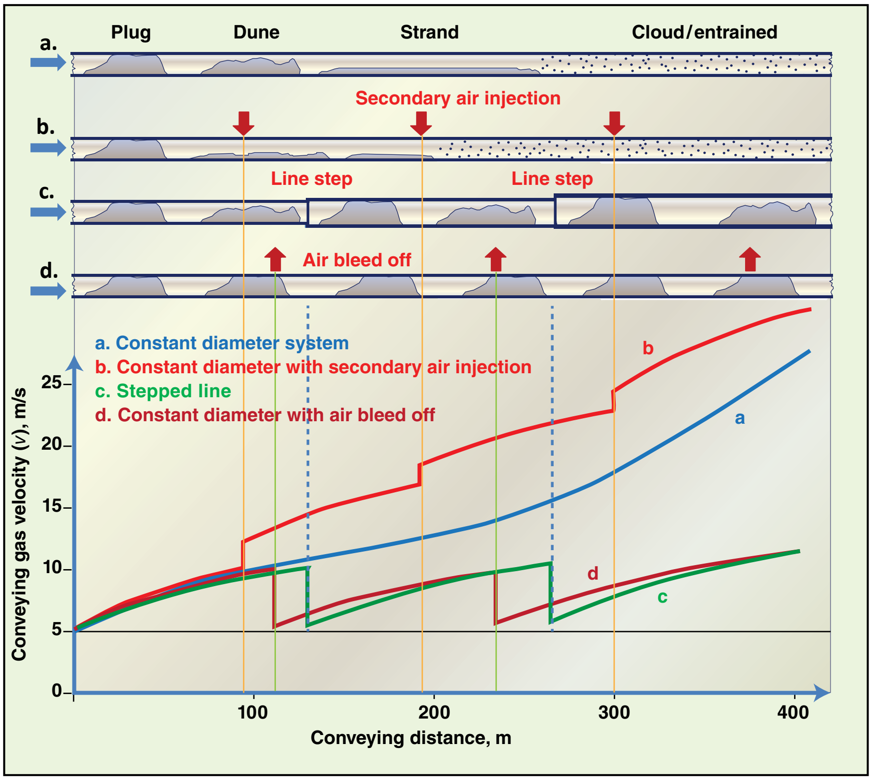


FIGURE 4. This figure provides a comparison of velocity profiles between various designs of dense-phase systems

Another option for optimizing the velocity profile without stepping the line is to use controlled leakage of conveying gas at single or multiple locations [*3*]. The air-leakage approach is equivalent to stepping the line as far as the velocity distribution is concerned, since the expansion of the air (and thus the volumetric flowrate) is compensated by the bleed-off. However, air-leakage increases the solids-loading ratio.

It becomes evident that the stability of a pneumatic conveying system must be evaluated mainly by two criteria: First, the availability of a sufficiently high conveying pressure of the conveying gas to keep the material moving, and second a stable velocity profile along the conveying line in accordance with the expected conveying mode and wear characteristics. For high-capacity, dense-phase systems, the minimization of shock loads from slugs impacting bends or other slugs may become a third criterion.

Figure 5 defines the acceptable velocity profile ranges for dilute-phase and dense-phase conveying. As shown for the dilute-phase case (red line), the extrapolation for the 250-mm-dia. conveying line beyond

TABLE 1. SUMMARY OF AIR MOVERS AND FLOW CONTROL OPTIONS								
	Conveying gas source and range			Methods for flowrate adjustment				
Air-mover type or compressed-air source	Typical mode of conveying	Pressure range, bar	Flowrate range m^3/h	RPM change (only for single system)	Orifice plate, Laval nozzle, flow-control valve	Inlet and outlet dampers, inlet vanes	Air bleed	Air-management system
Ejectors or eductors	Dilute	0.5	1,000	N/A	Yes	Yes	No	No
Fans	Dilute	< 0.2	< 7,000	No	No	Yes; also useful for smooth startup	Can result in instability or surging	No
Centrifugal blowers	Dilute	< 0.5	< 1,000	Yes	No	Yes; also useful for smooth startup	Can result in instability or surging	No
Rotary-lobe blowers	Dilute (Dense in certain cases)	< 1.0 (1.5)	< 10,000	Yes, preferable	Yes	Never	Yes; need stable control	Yes
Screw compressors (single-stage)	Dilute and dense	< 3.5	< 7,000	Yes, preferable	Yes	Never	Yes; more air-management options available	Yes
Turbocompressors	Mostly dense	< 4.5	< 14,000	Yes, preferable	Yes	No	Yes; more air-management options available	Yes
Plant air, net	Dilute and dense	< 6 (typical)	No limits	Not applicable (N/A)	Yes	N/A	N/A	Yes

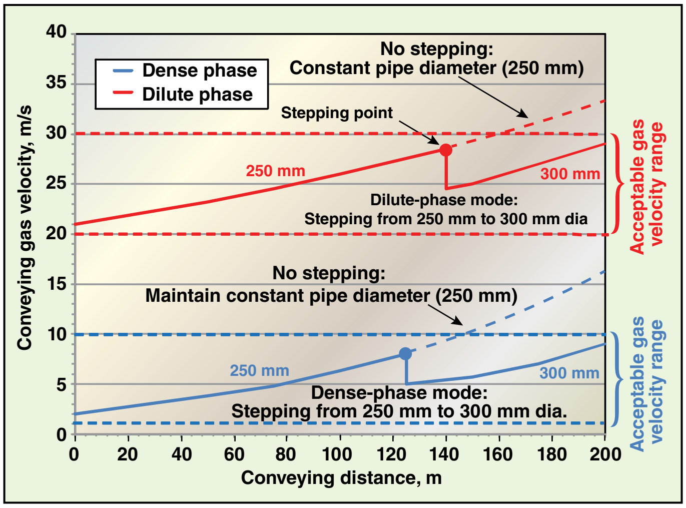


FIGURE 5. Shown here are conveying gas velocities in optimally designed dilute- and dense-phase conveying systems for polymer pellets, (conveying 50 ton/h, over a distance of 200 m)

the distance of 160 m would result in velocities outside the acceptable values (shown by the dashed lines in Figure 5). Similarly, for the dense-phase case (blue line), the threshold value is 150 m. This shows that by stepping the line (that is, increasing the line diameter) at an appropriate location, it is possible to attain a velocity profile within the acceptable range for the entire system. In general, the upper acceptable velocity limit depends on degradation characteristics of the specific polymer grade and the constraints on total power consumption.

Control requirements

Production plants are often multi-product plants with complex logistical requirements, as they handle many types and grades of bulk solids. For example, a single polymer production train will produce polymers that vary in density, melt index and additive packages, while systems designed for beaded carbon-black pellets handle products with different hardness due to different agglomeration processes. Operationally, different products must be sent to different destinations, at varying rates. It is difficult to design a system that will work at optimal conveying conditions for all products, production rates and conveying distances. To achieve this required flexibility and optimal conveying conditions, the conveying gas flowrate is typically adjusted for each situation. Both dilute- and dense-phase systems can benefit from an air-control system. The reasons and design rationales for these systems can be different; thus, they are discussed separately below.

Dilute-phase conveying

Dilute-phase conveying systems will always convey reliably as long as the gas velocity is maintained above saltation conditions at all locations along the conveying length. However, excess velocities will result in product degradation, system wear and higher power consumption. The optimal operating point for an unstepped system is when the gas velocity at the pickup location is maintained slightly above the saltation velocity. For stepped systems, one must also maintain the gas velocity above saltation conditions at each step location. Consider these factors:

1. Saltation velocity is a function of material properties and solids flowrate
2. The gas-delivery volume of the air mover (except for the plant network supply) depends on the system pressure drop or the conveying pressure
3. Absolute pressure at the pickup location affects the superficial gas velocity as per the Ideal Gas Law
4. Air leakage at the feeder (such as through rotary airlocks) depends on conveying pressure and must be compensated for

By taking all these factors into account, one may calculate the gas-flowrate setpoint that is required to maintain optimal gas velocity at the pickup location. The function of an automatic air-control system is to determine this setpoint and send the control signal to the hardware in the field. The next challenge is to identify the necessary hardware to achieve the desired flowrate at pickup (Figure 6). For blower or compressor air movers, three main types of control configurations can be found in practice, namely:

1. Bleeding off conveying gas downstream of the air mover (blower or compressor) to adjust the gas flowrate to the desired value
2. Using flow-control valves or (variable) Laval nozzles (sonic nozzles) to set the flowrate by partial circulation of compressed air back to the suction side of the air mover (blower or compressor)
3. Adjusting the speed of the air mover (blower or compressor) and changing the actual flowrate.

The gas-bleeding approach may the simplest option; however, it may compromise energy efficiency by venting previously compressed air. And, this approach is not suitable for conveying gases other than air, and for systems using fans as air movers. While the same energy considerations apply for gas recirculation, the control of the pickup velocity using a control valve or Laval nozzle tends to be a more reliable approach and is commonly implemented in large-scale systems. Air-mover speed control is the most energy-efficient approach of the three options outlined above, but this approach may be limited by motor size and permissible air-mover speed (see Table 1 for guidance).

Calculation of pickup velocity. Velocity at the pickup can be estimated by performing a mass balance of conveying gas and correcting for pressure and temperature conditions at the pickup location.

$$\left[\dot{m}_f\right]_{pickup} = \left[\dot{m}_f\right]_{blower\ inlet} - \left[\dot{m}_f\right]_{bleed} - \left[\dot{m}_f\right]_{feeder\ leakage} \quad (1)$$

$$\left[V_{pickup}\right] = \left[\dot{m}_f / \left(\rho_f \times A\right)\right]_{pickup} \quad (2)$$

Where:
$\dot{m}_f$ = The mass flowrate of the gas, kg/s
ρ_f = The density of the gas, kg/m^3
A = The flow cross-section of the pipe, m^2

Dense-phase conveying

The key objective of an air-control (or air-management) system in dense-phase systems is to maintain the operating point within the stable zone (Figure 7). The stable region is bounded by the conveying limit on the low end, and the unstable region on the high end of gas flowrate. These limits are derived from the state diagram (Figure 2), and the maximum available pressure comes from air mover characteristics. Even though the specifics of air-control systems remain the know-how of conveying-system suppliers, a general outline on how such a system works is provided below.

The basis for determining the permissible operating window and the respective boundary lines come from the pneumatic system calculation and the system state diagram (shown in Figure 2). These calculations are performed for the respective line routing, and minimum as well as maximum conveying rates, for a given material. The acceptable range of operating parameters within the gas-management system is taken from these limits by applying some safety margins resulting from practical experience. Thus, the acceptable operating window or the stable zone is demarcated by the green lines shown in Figure 7.

When starting the operation of the conveying system for a solids flowrate equal to $\dot{m}_{S2}$ initially a conveying gas flowrate according to the operating Point *A* (as shown in Figure 7) is set by the programmable logic controller (PLC). This corresponds to maximum acceptable terminal conveying velocity at minimum permissible capacity for the shortest conveying distance.

The flowrate, temperature and conveying pressure are measured to calculate the actual pickup velocity. This initial pickup velocity is at the upper limit of the operating window. Then the air flowrate will be reduced in increments, and the

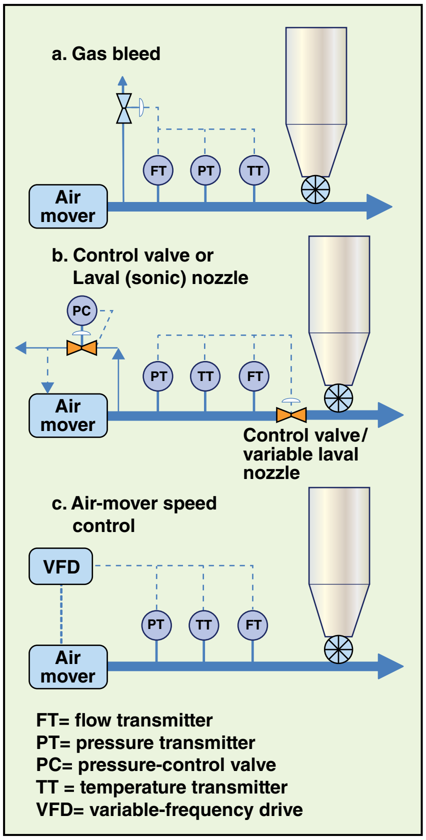


FIGURE 6. Some general concepts for controlling pickup velocity in pneumatic conveying systems are presented here

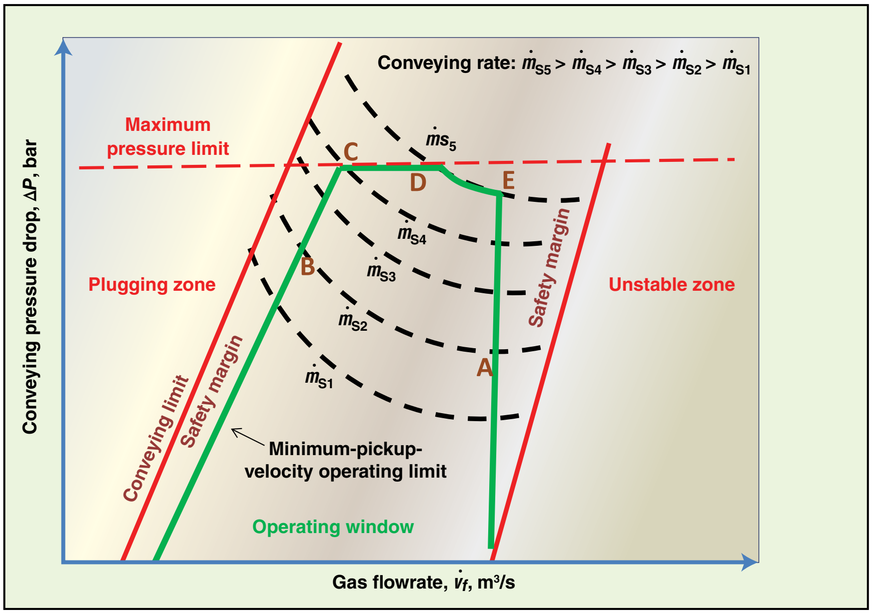


FIGURE 7. This figure shows a typical stable operating window for dense-phase conveying. The data points represented by letters *A* through *E* are described in text

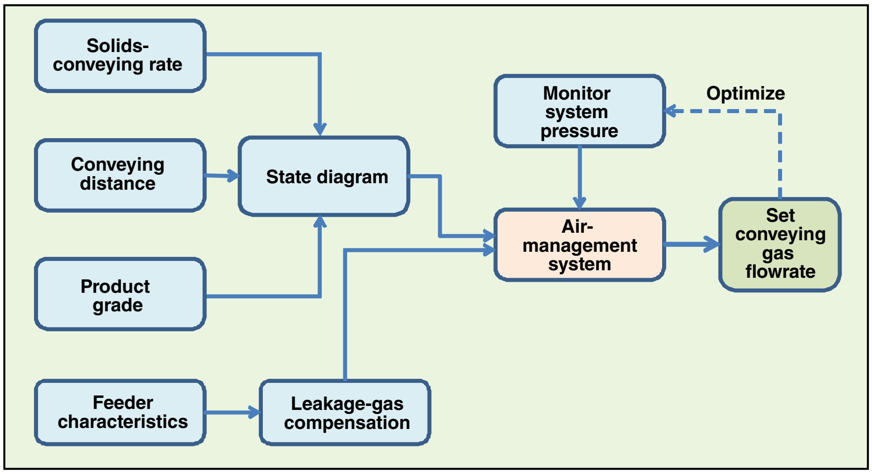


FIGURE 8. When designing an air-control system for pneumatic conveying, it is useful to follow an internal logic and strategy assessment, such as the one shown here

operating parameters at the new operating point (further to the left) are checked again. This control sequence is continued until the minimum pickup velocity on the left-hand edge of the operating window at Point *B* (and thus the pre-set limit) is reached.

If the pressure fluctuations that are normal in dense-phase conveying increase the pressure to an operating point that exceeds the acceptable operating window, then the controller allows a higher air flowrate and thus moves the operating point to the right until it reaches again the line of minimum pickup velocity. The controller follows the line of the minimum pickup velocity, as programmed in the controller.

When the conveying capacity or conveying distance is increased, the conveying pressure and the leakage flowrate increase as well — as does the gas density, thereby lowering the actual velocity at the pickup point. To maintain the required pickup gas velocity, the gas flowrate must be increased accordingly. The operating point slowly follows the line of minimum pickup velocity until the maximum acceptable conveying pressure is reached, at Point *C*. Note that the line *BC* must include gas leakage from the feeder and pressure-induced density changes. Since now the maximum available (permissible) pressure is reached in Point *C*, no further increase in pressure is acceptable.

If the pressure requirement increases beyond the plateau representing the maximum permissible pressure — for instance, due to higher pressure fluctuations, increased capacity or poorer conveying characteristics due to humidity — then this must be compensated by increasing the gas flowrate along the horizontal plateau until reaching Point *D*. Any further increase in gas flowrate will result — along the respective line in the state diagram — in a reduction of pressure drop until the maximum terminal velocity is reached at Point *E*.

If no operating point within the upper limitation of the operating window (line from *C* via *D* to *E*) can be reached, then the rotary feeder speed has to be reduced to achieve a lower mass flowrate and consequently lower conveying pressure.

The dense-phase conveying characteristics can vary significantly between various materials. If the grade, capacity and distance are known, then the respective operating line can be chosen and the air volume flowrate can be adjusted to a predefined value — either in the center of the stable region, or closer to either the left-hand limit (for minimum conveying velocity) or the right-hand limit (if the available pressure is limited).

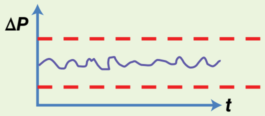
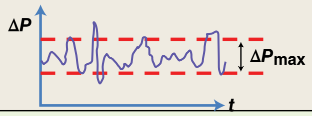
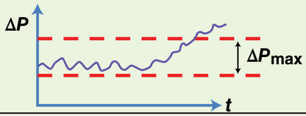
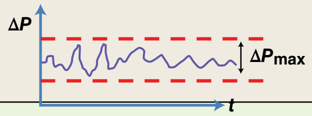
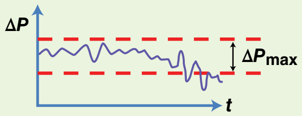
The control logic (Figure 8) is typically programmed in a PLC and provided as a black-box as part of the gas-management system. The parameters are implemented into the controller during commissioning. Alternatively, this control logic can be implemented into the plant-wide distributed control system (DCS).

The gas-management system described achieves a minimum pickup velocity and ensures stable operating conditions based on reliable system calculations. The shape of the operating window will have to be adjusted to the conveying characteristics of individual bulk solids. Since large-capacity, dense-phase conveying systems are exposed to considerable pipe forces, another appropriate criterion to use during system operation is to take steps to minimize shock loads in the piping system. Typically, large pipe forces coincide with strong pressure fluctuations. Thus, the variability in conveying pressure can be used as a stability criterion and the gas flowrate can be adjusted further within the operating window by minimizing pressure fluctuations.

With a control system that uses pressure fluctuations to reduce pipe forces, it is important to allow the system to run smoothly and not to overreact too quickly to respective pressure fluctuations. The control system should not react to individual pressure spikes, but it should analyze the overall pressure trends and nature of fluctuations before prescribing a control action (Figure 9). The pressure signals can be analyzed using time series analysis methods (for example, Fourier transform and auto-correlation). Due to inconsistency in conveying behavior and temporary pressure peaks reducing the actual gas velocity and thus influencing the stability of the conveying system, some additional control mechanisms are required to respond to these inconsistencies. An increase in conveying pressure can, for example, be caused by a higher humidity resulting from a dryer malfunction. An increased conveying pressure over an extended period of time must be answered by an increase in conveying gas flowrate to increase the velocity and to reduce the pressure to a lower value. Such control strategies (see Figure 9) may be implemented into an air-control system.

All the controls described so far (see Figure 6) are meant to adjust the conveying gas flow by setting respective flow valves. Gas flow from a compressor, however, can also be adjusted by changing the speed of the compressor via a variable-frequency drive (VFD). While this technology has traditionally been relatively expensive, the use of VFD control has become more economical in recent years. Additionally, no extra pressure drop from the gas management system has to be overcome, making this concept also a viable option for system upgrades.

DIAGNOSTIC AND CONTROL STRATEGY FOR DENSE PHASE SYSTEM BASED ON PRESSURE FLUCTUATIONS MEASUREMENT

Pressure measurement	Control strategy
	Pressure fluctuations within acceptable limits, no trend, no big spikes • stable operating conditions • no adjustment of conveying gas flow needed
	Pressure fluctuations exceed permissible range or total pressure exceeds limits, strong fluctuations, no trend: • close to instable operating conditions • reduce conveying gas flowrate to leave instable zone
	Pressure fluctuations within acceptable limits, but trend towards higher total pressure (increased flowrate, humidity): • approaching plugging limit • increase conveying gas flowrate
	Pressure fluctuations decrease to acceptable limits, stable operating conditions: • no more adjustments needed • maintain current conveying gas flowrate
	Pressure fluctuations increase and exceed acceptable limits with trend towards lower total pressure (reduced flowrate, low solids-to-air ratio): • approaching instable zone • reduce conveying gas flowrate to return to stable operating window

Note: Dashed lines represent acceptable operating limits

FIGURE 9. This figure provides a comparison of various diagnostic and control strategies for dense-phase systems, based on pressure-fluctuation measurements and analysis. Smart air-control systems should incorporate these strategies

Line purge

When making a change in grade or destination of a pneumatic conveying system it is important to clean the line of residual solids. This is rather simple for most dilute-phase systems since the individual particles are carried by the gas stream. Thus, it only takes a certain period of operation until the line is "blown" clean. However, problems do occur when using special bends, since these can create a pocket of solids or exhibit a wider cross-section, thus requiring additional gas flow for line cleaning. However, in dense-phase conveying systems the conveying gas flow is lower than the settling velocity and thus is not sufficient to clean the conveying line without a considerably larger gas flowrate. This ad-

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ditional gas flow can be generated either by temporarily using a spare compressor or blower, or by sucking in additional air from the environment using a Venturi. If the conveying gas is taken from the plant air supply, then the gas-management system has to allow for a purging cycle with a higher gas flowrate, provided that the plant air supply has sufficient capacity. The use of pressure reservoirs only helps for smaller systems, since most of these purge tanks have a relatively small volume that is insufficient to clean long and large conveying lines.

Closing thoughts

Reliable operation of pneumatic conveying systems requires knowledge of the state diagram and desirable operating windows. This is based on conveying characteristics that are either measured in a test facility or generated while operating a similar industrial system. Velocity is the key control variable for dilute-phase systems. The velocity control (or airflow control) can be accomplished in many ways depending of the type of air mover.

A more-sophisticated control system is required for dense-phase conveying where the stable operating zone, line forces, system stability, startup and shutdown must be taken into account. Today, suppliers of dense-phase conveying systems have developed expertise that is incorporated into specialized hardware and software to appropriately manage these variables. ■

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Learning about spray technologies

With 38 years of experience, Mike Resetarits consults on distillation, absorption and extraction processes. Each month, Mike shares his first-hand experiences with *CE* readers

Spray nozzles are very useful tools with a simple concept and sometimes complex design. Earlier this year, I attended the 26th Annual ILASS (Institute for Liquid Atomization and Spray Systems; www.ilass.org) Conference in Portland, Ore., which was held on May 19–21. There were roughly 100 attendees, including representatives from Canada, Germany and Mexico, as well as the U.S.

Over 50 presentations were given by speakers from universities, think tanks, government agencies and industry. The variety of topics covered is illustrated in the following brief descriptions of some of those presentations: Spray Systems Co. (Wheaton, Ill; www.spray.com) used computational fluid dynamics (CFD) to model spray columns for wet fluegas desulfurization (WFGD) units; they also used a variety of spray evaluation devices to study the application of a thin layer of peanut oil onto a flat surface (regarding the latter study, a CFD analysis of the spray did not predict the spray angle very well).

Kathleen Feigl, of the Michigan Technological University (Houghton, Mich.; www.mtu.edu), addressed small water droplets entering a crossflowing hydrocarbon stream using numerical simulations; the study has relevance to membrane devices. Anne Geppert (University of Stuttgart; www.uni-stuttgart.de) employed a two-perspective high-speed shadowgraphy imaging system to show the crown of thin liquid that is formed when a falling droplet impacts a horizontal surface; her study has relevance to the reduction of droplet footprints in diesel engines. Barry Scharfman, of the Massachusetts Institute of Technology (MIT; Cambridge; web.mit.edu), described a new technique where multiple cameras are used with light-field imaging and synthetic-aperture (SA) refocusing techniques to resolve 3-D spray fields over time.

FRI gave a presentation regarding past and near-future studies of hydrocarbon liquid sprays, with counter-flowing hydrocarbon vapor streams. FRI performs such work in its 4-ft-dia. column using C4, C6 and C8 hydrocarbon vapor streams at column pressures ranging from 75 mm Hga to 400 psia. FRI's colleagues at Oklahoma State University gave a presentation regarding the use of low-pressure-drop spray columns for fluegas CO_2 removal.

The ILASS meeting gave the attendees the opportunity to learn about a large number of devices and technologies used for evaluating sprays, such as: phase Doppler particle analyzers (PDPAs); phase Doppler interferometers (PDIs); laser-induced fluorescence (LIF); X-ray computed tomography (CT); particle image velocimetry (PIV); laser sheet imaging; and, of course CFD.

I encourage anyone whose job includes the design, use, evaluation, specification or troubleshooting of spray nozzles to consider attending future ILASS meetings. You will certainly meet everyone that you need to know. ■

Mike Resetarits

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15	30	45	60	75	90	105	120	135	150	165	180	195	210	225	240	255	270	285	300	315	330	345	360	375	390	405	420	435	450	465	480	495	510	525	540	555	570	585	600

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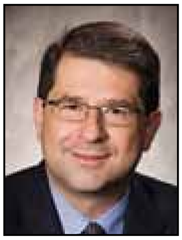
People

OCTOBER WHO'S WHO


Monge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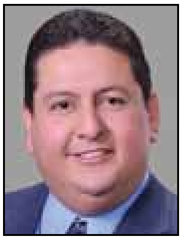
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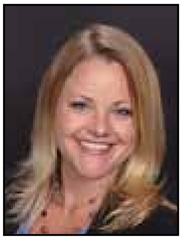
Ballard


Ockun

Sartorius Stedim Biotech S.A. (Aubagne, France) welcomes *Miriam Monge* as director of marketing for integrated solutions.

Jose Varela becomes vice president and general manager of the personal safety division of **3M Co.** (St. Paul, Minn.).

Luis López-Remón is now the head of the leather business unit of specialty chemicals producer **Lanxess AG** (Cologne, Germany), succeeding *Markus Eckert*, who is now heading up the corporate development group function.

Cem Onus is promoted to managing director of systems for **Dekra Certification, Inc.** (Chalfont, Pa.), the U.S.-based division of **Dekra Certification Group** (Stuttgart, Germany), an accredited certification body for international management systems.

Greene's Energy Group LLC (Houston) promotes *Ricardo "BJ" Rivera* to district manager for two of its product lines (Testco Production BOP Testing and Guardian Wellhead Protection and Rentals).

Toray Plastics (Americas), Inc. (North Kingstown, R.I.) welcomes two new business managers: *Anne Ballard* and *Gregg Ockun,* who will each handle different product lines.

Terje Bakken becomes managing director, heading up marketing and sales, for fertilizer company **EuroChem** (Moscow, Russia). ■

Suzanne Shelley

BUSINESS NEWS

PLANT WATCH

Lanxess expands new plant for inorganic pigments in Ningbo

September 11, 2014 — Lanxess AG (Cologne, Germany; www.lanxess.com) is adding a mixing and milling plant to the pigment plant already under construction in Ningbo, China. The new pigment plant will have an initial capacity of 25,000 metric tons per year (m.t./yr) of iron oxide red pigments. The mixing and milling plant will have a capacity of 70,000 m.t./yr. The plants are scheduled to start production in the first quarter of 2016.

Huber Engineered Materials expands alumina trihydrate capacity in Arkansas

September 10, 2014 — Huber Engineered Materials (Atlanta, Ga.; www.hubermaterials.com) has increased capacity at its precipitated alumina trihydrate plant in Bauxite, Ark. by 30%. A second phase of investment in capacity expansion in Bauxite is targeted for completion in 2015.

Momentive completes production facility for epoxy resins and curing agents

September 9, 2014 — Momentive Specialty Chemicals Inc. (Columbus, Ohio; www.momentive.com) has completed construction of a facility that will produce epoxy resins and curing agents in Itatiba, Brazil. The epoxy resins and curing agents will be used for large-diameter wind-turbine blades.

Exxon affiliate Esso Norge to build new processing unit at Slagen refinery

September 8, 2014 — ExxonMobil Corp. (Irving, Tex.; www.exxonmobil.com) affiliate Esso Norge AS has announced plans to install a new processing unit at the Slagen petroleum refinery to enable production of high-quality vacuum gas oil. The new residual flash tower unit will replace production of heavy fuel oil with lighter gas oil.

Topsøe to design large-scale fertilizer plant in Turkmenistan

September 2, 2014 — In collaboration with Mitsubishi Heavy Industries Ltd. (Tokyo; www.mhi-global.com), Haldor Topsøe A/S (Lyngby, Denmark; www.topsoe.com) will design a new ammonia plant for a major fertilizer project in Garabogaz, Turkmenistan. The fertilizer plant is scheduled to go onstream in June 2018. The plant will have a capacity of 2,000 m.t./d of ammonia and 3,500 m.t./d of urea.

CB&I awarded contract for propylene and comonomer production in China

August 26, 2014 — CB&I (The Woodlands, Tex.; www.cbi.com) has been awarded a contract by Shenhua Ningxia Coal Industry Group Co. for the license and engineering design of a petrochemicals complex to be built in Lingwu, Yinchuan City, Ningxia, China. The complex will produce 196,000 m.t./yr of polymer-grade propylene and 20,000 m.t./yr of comonomer-grade 1-butene.

LyondellBasell to build new production plant for propylene oxide and TBA

August 25, 2014 — LyondellBasell (Rotterdam, the Netherlands; www.lyondellbasell.com) plans to build a world-scale plant on the U.S. Gulf Coast with a capacity of around 400,000 m.t./yr of propylene oxide (PO) and around 900,000 m.t./yr of tertiary butyl alcohol (TBA) and its derivatives. The preliminary timetable is to have the plant operational in 2019.

Gemini HDPE selects KBR for EPC services at new HDPE facility in Texas

August 25, 2014 — KBR Inc. (Houston; www.kbr.com) has been awarded a contract from Gemini HDPE LLC, a joint venture (JV) between Sasol Chemicals North America LLC (Westlake, La.; www.sasolnorthamerica.com) and Ineos Olefins & Polymers USA (La Porte, Tex.; www.ineos.com), to provide engineering, procurement and construction (EPC) services for a new high-density polyethylene (HDPE) facility to be located at Ineos' Battleground Manufacturing Complex in La Porte, Tex.

MERGERS AND ACQUISITIONS

Eastman to acquire specialty chemicals company Taminco for $2.8 billion

September 11, 2014 — Eastman Chemical Co. (Kingsport, Tenn.; www.eastman.com) has entered into an agreement to acquire Taminco Corp. (Allentown, Pa.; www.taminco.com), a global specialty chemical company. The total transaction value is $2.8 billion.

WorleyParsons to acquire hydrocarbons-management consulting firm

September 9, 2014 — WorleyParsons Ltd. (North Sydney, Australia; www.worleyparsons.com) will acquire MTG, Ltd., a management-consulting firm specializing in operational-performance improvement across many industries. Completion of the acquisition is expected by the end of October 2014.

Solvay expands its specialty polymers offerings with Ryton PPS acquisition

September 4, 2014 — Solvay S.A. (Brussels, Belgium; www.solvay.com) has signed an agreement to buy the Ryton PPS (polyphenylene sulfide) business from Chevron Phillips Chemical Co. (The Woodlands, Tex.; www.cpchem.com) for $220 million. The transaction includes two Ryton PPS resin-manufacturing units in Borger, Tex., its pilot plant and R&D laboratories in Bartlesville, Okla., and a compounding plant in Kallo-Beveren, Belgium.

A. Schulman acquires Australia-based Compco for $6.7 million

September 2, 2014 — A. Schulman, Inc. (Akron, Ohio; www.aschulman.com) has acquired Compco Pty. Ltd., located near Melbourne, Australia, for $6.7 million in cash. Compco manufactures a variety of plastic compounds and products, including masterbatches and custom performance colors. Key markets include packaging, wire, cable and pipe.

Albemarle and ICL form JV for manufacture of flame retardants

August 29, 2014 — Albemarle Corp. (Baton Rouge, La.; www.albemarle.com) and ICL (Tel Aviv, Israel; www.icl-group.com) will establish a JV for the production of flame retardants designed to replace hexabromocyclododecane (HBCD), which is being phased out in the European Union, Japan and other countries. The JV will own and operate an existing plant in the Netherlands with a capacity of 2,400 m.t./yr of HBCD, and a plant in Israel, with capacity of 10,000 m.t./yr, which is scheduled to come online in the 4th quarter of 2014.

Umicore acquires Ohio-based CP Chemicals Group

August 25, 2014 — Umicore N.V. (Brussels, Belgium; www.umicore.com) has acquired CP Chemicals Group, LP (Wickliffe, Ohio; www.cpchemicalsgroup.com), a refiner and recycler of cobalt- and nickel-containing secondary materials. The company also transforms these materials into chemicals for the catalyst, petrochemical and refining industries, and recycles rhenium from superalloy turbine blades used in the aviation industry. The business will be integrated into Umicore's Cobalt & Specialty Materials business unit. ■

Mary Page Bailey

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FOR MORE ECONOMIC INDICATORS, SEE NEXT PAGE

Economic Indicators

2012 — 2013 — 2014

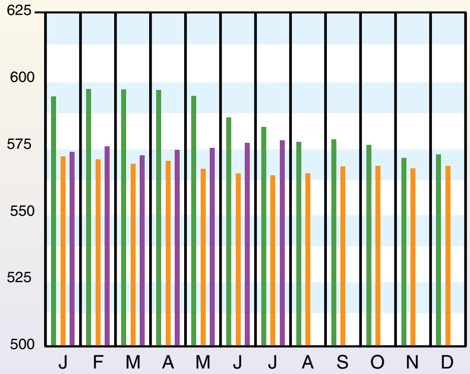
DOWNLOAD THE *CEPCI* TWO WEEKS SOONER AT *WWW.CHEMENGONLINE.COM/PCI*

CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957–59 = 100)	July '14 Prelim.	June '14 Final	July '13 Final
***CE* Index**	577.0	576.2	564.0
Equipment	700.4	700.1	682.0
Heat exchangers & tanks	640.3	638.0	620.7
Process machinery	667.6	673.8	655.0
Pipes, valves & fittings	878.2	880.3	861.8
Process instruments	413.4	410.8	407.4
Pumps & compressors	938.8	938.2	920.7
Electrical equipment	516.1	515.3	512.4
Structural supports & misc	771.1	770.0	729.8
Construction labor	322.4	319.8	320.2
Buildings	544.5	543.4	531.1
Engineering & supervision	321.1	320.6	324.1

Annual Index:

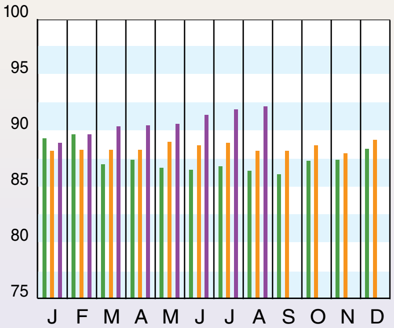
2006 = 499.6
2007 = 525.4
2008 = 575.4
2009 = 521.9
2010 = 550.8
2011 = 585.7
2012 = 584.6
2013 = 567.3



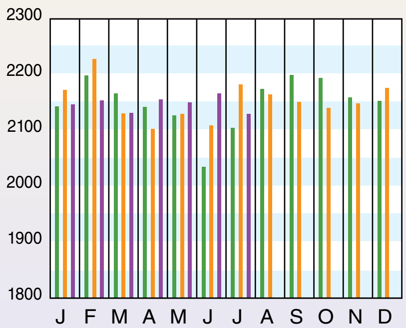
CURRENT BUSINESS INDICATORS*

	LATEST			PREVIOUS						YEAR AGO		
CPI output index (2007 = 100)	Aug.'14	=	92.2	Jul.'14	=	91.9	Jun.'14	=	91.6	Jul.'13	=	88.8
CPI value of output, $ billions	Jul.'14	=	2,129.9	Jun.'14	=	2,161.2	May '14	=	2,150.6	Jun.'13	=	2,171.8
CPI operating rate, %	Aug.'14	=	77.4	Jul.'14	=	77.3	Jun.'14	=	77.1	Jul.'13	=	75.6
Producer prices, industrial chemicals (1982 = 100)	Aug.'14	=	293.9	Jul.'14	=	293.2	Jun.'14	=	288.9	Jul.'13	=	299.3
Industrial Production in Manufacturing (2007 = 100)	Aug.'14	=	100.2	Jul.'14	=	100.6	Jun.'14	=	99.8	Jul.'13	=	96.7
Hourly earnings index, chemical & allied products (1992 = 100)	Aug.'14	=	156.1	Jul.'14	=	156.9	Jun.'14	=	157.1	Jul.'13	=	156.3
Productivity index, chemicals & allied products (1992 = 100)	Aug.'14	=	107.3	Jul.'14	=	108.0	Jun.'14	=	107.6	Jul.'13	=	106.7

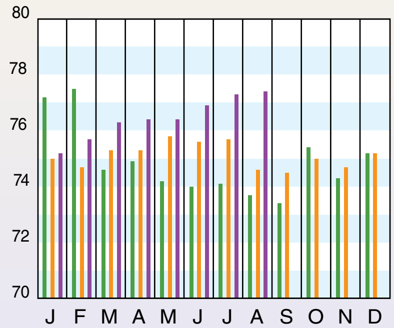
CPI OUTPUT INDEX (2007 = 100)



CPI OUTPUT VALUE ($ BILLIONS)



CPI OPERATING RATE (%)



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

HIGHLIGHTS FROM RECENT ACC ECONOMIC DATA

The Organization for Economic Cooperation and Development (OECD; Paris; www.oecd.org) released its global composite leading indicator (CLI) for July, and the data "point to stable growth momentum in most major economies," according to one of a number of recent Weekly Chemistry and Economic Reports from the American Chemistry Council (ACC; Washington, D.C.; www.americanchemistry.com). The OECD CLI+6 (leading indicators for the OECD member countries plus six major non-OECD economies) increased 0.1% in July and is now up to 3.7% over its level from a year ago, the ACC report says.

In other recent weekly reports, ACC reported on chemical-company equity performance, specialty chemical volumes and others. ACC noted that the S&P index for chemical companies advanced by 3.8% in August, matching the 3.8% rebound experienced by the wider S&P 500. Specialty chemical market volumes rose 1.0% in July, following a 0.8% rise in June. Of the 28 specialty chemical markets monitored by ACC, 23 expanded in July. The overall specialty chemicals volume index was up 5.3% year-over-year, on a three-month-moving average basis, the ACC report says.

In the U.S., ACC says construction spending on new chemical manufacturing facilities has surged to new all-time-high pace to take advantage of abundant natural gas and natural-gas liquids (NGL) supplies in the U.S.

The Chemical Activity Barometer (CAB), a leading economic indicator created by ACC, continued to see moderated upward growth in August, with a 0.2% gain over July, as measured on a three-month-moving-average (3MMA) basis. ❑

CURRENT TRENDS

The preliminary value for the July *CE* Plant Cost Index (CEPCI; top; the most recent available) rose 0.14% from the final June value, making it the fourth consecutive monthly gain. The Equipment, Construction Labor, Business and Engineering & Supervision subindices all saw gains in the July preliminary numbers. The small gain in the Equipment subindex was primarily accounted for by an increase in the Process Instruments subcategory offsetting declines in other areas. The overall July PCI value stands at 2.3% higher than its value from July of last year. Meanwhile, updated values for the Current Business Indicators (CBI) from IHS Global Insight (middle) show that the CPI output index and CPI value of output edged up. ❑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