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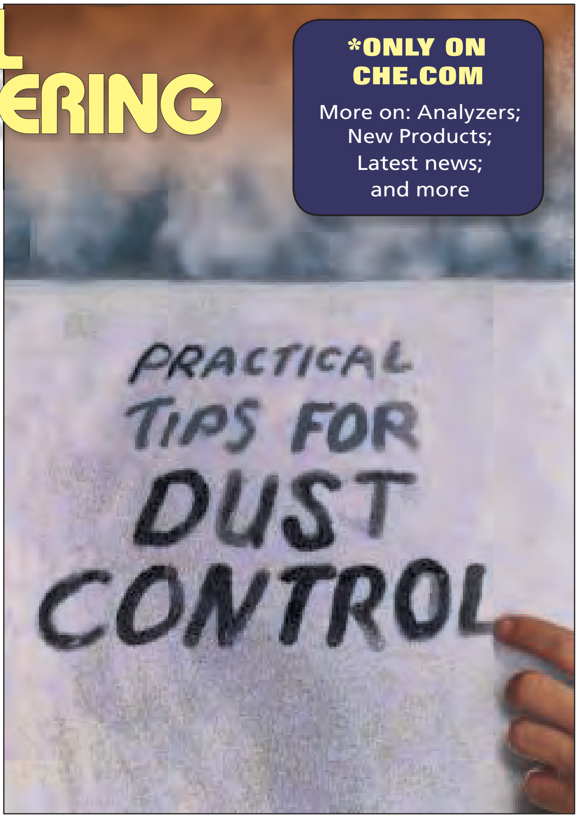

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BPA

Editor's Page

Are you ready for inspection?

Leading up to this month's 2012 U.S. Presidential election, the legislative landscape has been relatively uneventful. On top of their preoccupation with the election campaigns, lawmakers on both sides of the political spectrum have been reluctant to pin their agendas to any bill that might significantly alienate large groups of voters. Nevertheless, two relatively significant changes are coming down the pike for hazardous-chemical manufacturers in the U.S. Both of them are coming from a group that does not observe an immediate impact from the election cycle — the U.S. Occupational Safety & Health Admin. (OSHA; Washington, D.C.; www.osha.gov) — and both are being addressed in the ChemInnovations conference program later this month (New Orleans, La.; November 14–15; www.cpievent.com).

Chemical Facilities National Emphasis Program (NEP). The first change is OSHA's Chemical Facilities NEP, which outlines a new approach for conducting site inspections for the agency's Process Safety Management (PSM) of Highly Hazardous Chemicals (29 CFR 1910.119). Part of the new approach is to focus on whether a company's written PSM program is actually being implemented. The program is an expansion of a 2009 pilot program that covered a limited number of chemical facilities and is similar to OSHA's NEP for petroleum refineries. Announced last November, the Chemical NEP applies to over 6,000 facilities that manufacture highly hazardous chemicals.

Since there is no deadline or formal inspection schedule, however, the majority of the anxiety at each facility is centered around the simple questions of "if" and "when" an inspection might arise. "It could be next week or next year. No one really knows," says David Whitaker, a partner at Kean Miller LLP (New Orleans, La.; www.keanmiller.com) and speaker at ChemInnovations. For that reason, the most important thing you can do is be prepared, he says. At ChemInnovations, Whitaker will help attendees understand what the Chemical NEP means for them and how to be prepared for an inspection if it happens. Meanwhile, his colleague Steven Pereira, principal at Professional Safety Associates LLC (Denham Springs, La.; www.professionalsafety.com), will present his experience with over 50 PSM audits in the petrochemical and petroleum-refining industries and highlight typical "red flags" that get OSHA's attention.

Hazard Communication Standard (HCS). The second change is a revision to OSHA's HCS, which for the first time includes combustible dust in the definition of hazardous chemicals, and now requires training to specifically include combustible dust hazards. Employers will be required to train their employees by December 2013, with full implementation of the rule in 2015.

In his presentation, Impending Changes to OSHA's Hazard Communication Standard, Steven Luzik, senior process safety specialist for Chilworth Technology, Inc. (Princeton, N.J.; www.chilworth.com) will provide specific details regarding the revised standard, including the following three major changes to the previous version: (1) Hazard classification: The revised standard specifies criteria for classification of health and physical hazards, as well as classification of mixtures; (2) Labels: Chemical manufacturers and importers will now be required to provide a label that includes a harmonized signal word, pictogram and hazard statement for each hazard class and category. Precautionary statements must also be provided. Chemical manufacturers and importers will be required to evaluate the hazards of the chemicals they produce or import, and prepare labels and safety data sheets to convey the hazard information to their downstream customers; (3) Safety Data Sheets (SDSs): MSDSs will now be referred to as SDSs. They will now have a specified 16-section format. ■

Rebekkah Marshall

Letters

Submitting manuscripts to CE

Practical information. First and foremost, our readers look to us for practical information. These individuals want concise factual information that aids in solving real problems. They do not look to us for abstract theoretical treatises, vague general discussions or reviews of previously published material. In other words, we prefer and accept "how to" articles rather than purely descriptive ones. Most of our articles fit in one of the following categories:

- Process equipment selection, design or specification
- Plant operations and maintenance
- Process and equipment optimization
- Economic evaluation
- Project management
- Regulatory compliance and safety considerations

Broadly applicable. CE articles should appeal to a relatively wide section of our readers, who are chemical engineers working throughout the chemical process industries, as opposed to just one sector of them.

Non-promotional. Outside authored articles must make no mention of nor show favoritism toward specific products or vendors.

Exclusive. We only publish manuscripts that are offered to us exclusively. In other words, submit your manuscript to only one magazine at a time!

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Artwork. Please include all artwork and tables with your manuscript and obtain any necessary legal clearance beforehand. Photographs must be at least 300 dpi or greater.

Length. We generally look for manuscripts in the 2,000–5,000 word range.

Date. The timing depends on what your schedule allows.

Questions to consider as you write

- Is the idea or manuscript timely or interpretive, rather than just a rehash of old material?
- Is the idea or manuscript aimed at helping the non-specialist become conversant with the subject, rather than being written for another expert?
- Does the material help readers in decision-making, in technical administration, or in policy formulation?
- Will it enable readers to accelerate their professional development?

If so, then you're on the right track.

Postscripts, corrections*

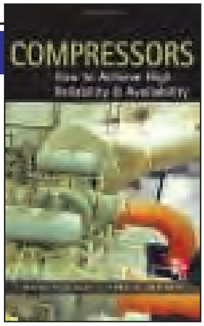
September, Cooling Water Outlet Temperature: Evaluating the Best Maximum Value, pp. 46–50, contained two errors:

1. Equation (19) should read $D = \log (TH) - 0.4$
2. Table 2 is missing decimal points in all numbers on both the x-axis and the y-axis

October, Who's Who, p. 62, had two spelling errors: Blachoh Fluid Control should be Blacoh Fluid Control, and the headquarters of CST International are in Lenexa, Kan. not Lexana. ■

* The online versions of these article have been amended and can be found at http://www.che.com/archives/extras/ps_and_corrections/

Bookshelf



Compressors: How to Achieve High Reliability & Availability. By Heinz P. Bloch and Fred K. Geitner. McGraw-Hill. 1221 Avenue of the Americas, New York, NY 10020. Web: mcgraw-hill.com. 2012. 268 pages. $50.00.

Reviewed by Amin Almasi,
WorleyParsons Services Pty. Ltd., Australia

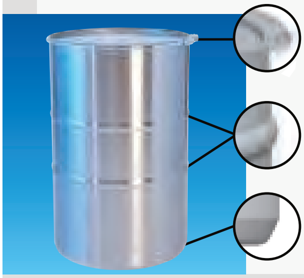
Large numbers of compressors fail in CPI (chemical process industries) plants every year, with some experiencing catastrophic failures that incur extensive damage or personnel injuries. Many of the numerous reference books on compressors discuss theoretical or mathematical aspects of compressors, or focus on stereotyped or narrow fields related to compressors. They have generally failed to frame the key issues affecting the operation, availability, reliability and application of these complex machines. Many such reference books are either too academic or too vague and neglect practical matters.

With this handbook, authors Heinz Bloch — one of the best-known machinery and reliability specialists in the world — and co-author Fred Geitner, have produced an impressive and ambitious work that is strikingly different than other books focusing on compressor reliability and availability. This relatively short book offers extremely useful guidelines and practical notes in a compact and useful form. The book's strength lies firmly in its sharply focused and well-considered paragraphs, which are presented for both reciprocating and centrifugal compressors.

The book would benefit from additional coverage on some new subjects related to centrifugal compressor reliability and availability, such as integrally geared centrifugal compressors, hermetically sealed centrifugal compressors, magnetic-bearings and others. Nonetheless, the book has earned a place as one of the best works on compressors. The practical knowledge and experience of the authors benefit this book greatly, in terms of their coverage of smart practices and applicable issues for most commonly used compressors. This book should be considered a valuable reference for all engineers who work with compressors. I intend to keep this book in my library as a reference for any new project.

After an introductory chapter that reviews compression principles and internal labyrinths, Chapter 2 provides the selection factors for process compressors (presenting, for example, selection criteria related to operating flexibility, capital cost, maintenance, efficiency, and others). Chapter 3 provides the operating characteristics of turbo-compressors and discusses important aspects of surge, compressor speed, temperature and pressure, gas properties and other effects on compressor operation.

Chapter 4 explores wet and dry gas seals for centrifugal compressors. Important topics, such as how gas seals function, seal safety and reliability, and common seal problems, are also covered in detail. Chapters 5 and 6 discuss good practices and applicable issues on bearing, stability, vibration guidelines, and lubrication and seal-oil systems.



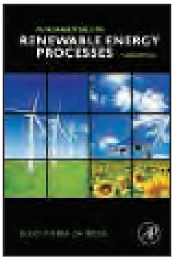
Bookshelf

Among the most useful sections are Chapters 7–9, which cover impellers and rotors, compressor maintenance and surveillance highlights, as well as inspection and rotor repair guidelines.

Chapters 10 and 11 deal with quality and failure analysis, and Chapter 12 presents an overview on reciprocating compressors. Chapters 13–17 provide details on reciprocating compressors, covering important topics such as operation, capacity control, maintenance, monitoring, troubleshooting and upgrading. Chapter 18 briefly reviews the training of compressor engineers.

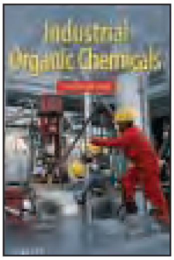
Atlas of Material Damage. By George Wypych. ChemTec Publishing, 38 Earswick Drive, Toronto, ON, Canada M1E 1C6. Web: chemtec.org. 2012. 450 pages. $325.00.

Fundamentals of Renewable Energy Processes. 3rd ed. By Aldo da Rosa. Elsevier Inc. 30 Corporate Drive, Burlington, MA 01803. Web: elsevier.com. 2012. 852 pages. $120.00.



Industrial Organic Chemicals. 3rd ed. By Harold Wittcoff, Bryan Reuben and Jeffery Plotkin. John Wiley & Sons Inc., 111 River Street, Hoboken, NJ 07030. Web: wiley.com. 2012. 840 pages. $149.95.

Practical Thermocouple Thermometry. 2nd ed. By Thomas Kerlin and Mitchell Johnson. International Society of Automation (ISA). 67 Alexander Drive, Research Triangle Park, NC 27709. Web: isa.org. 2012. 181 pages. $89.00.



Wonderful Life with the Elements: the Periodic Table Personified. By Bunpei Yorifuji. No Starch Press Inc., 38 Ringold Street, San Francisco, CA 94103. Web: nostarch.com. 2012. 205 pages. $17.95.

Introduction to Thermo-Fluid Systems Design. By André McDonald and Hugh Magande. John Wiley & Sons Inc., 111 River Street, Hoboken, NJ 07030. Web: wiley.com. 2012. 448 pages. $135.00.

Simulation. 5th ed. By Sheldon Ross. Elsevier Inc. 30 Corporate Drive, Burlington, MA 01803. Web: elsevier.com. 2012. 325 pages. $99.95. ■

Scott Jenkins

CHEMENTATOR

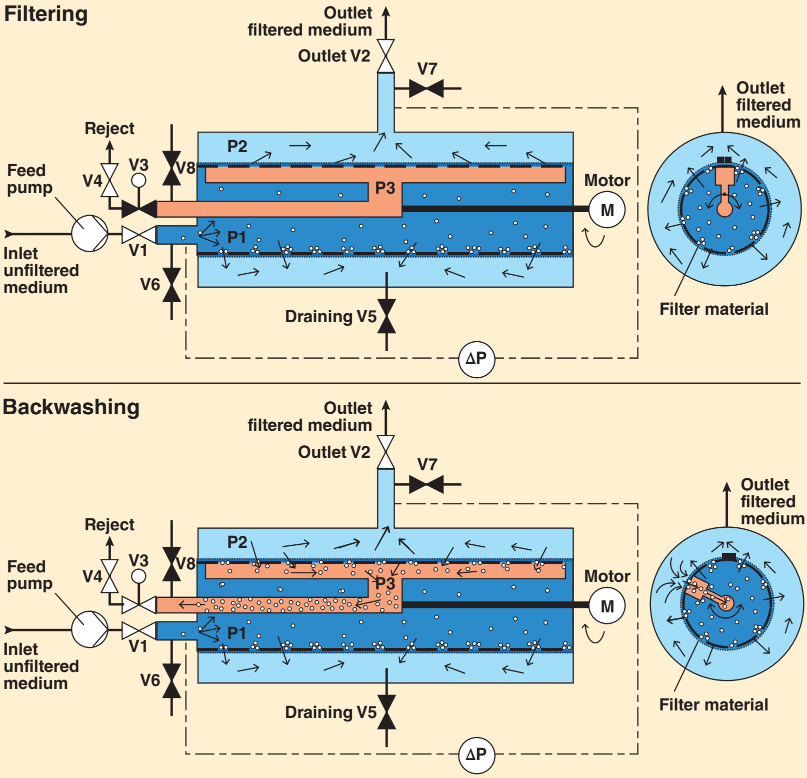
Edited by Gerald Ondrey | November 2012

This filtration system saves space, time and money

In the production of deionized (DI) water from river water, sand filters are commonly used to remove solid particles prior to the ion-exchange units. However, sand beds occupy a large space — as large as 3-m wide and over 5-m high — and need to operate with very low filtration speeds to ensure the output has a solids content of less than 1 mg/L (1 ppm) to prevent fouling of the ion-exchange resins. Sand filters also have to be cleaned periodically by backwashing with large volumes of water (160 m^3), which must be performed off line for about 20 min, so a second sand filter is required to operate while the other is being cleaned.

An alternative system that reduces the drawbacks of sand filters has been developed by Lenzing Technik GmbH (Lenzing, Austria; www.lenzing-technik.com). The OptiFil filter uses a very fine (10 µm) filter media (or even a metal-fiber fleece) on which a fine layer of particles forms within seconds at the beginning of the filtration cycle, thanks to a patented design, says product manager Stefan Strasser. This filter cake is periodically cleaned by partial backwash (diagram), which retains 95% of the filter area during backwashing and thus enables uninterrupted operation, Strasser says. Only 20–30 L of water is required for backwashing.

For DI applications, the investment costs for an OptiFil filter are as little as one half those needed for a sand filter, while operating costs are about a third, says Strasser, because the OptiFil requires less brackish water (1% versus 8% for a sand filter), consumes less air and is much less labor- and time-intensive for maintenance. Total space and weight requirements for the OptiFil are also reduced by 95%, he says.



The first application of the OptiFil filter for DI applications has been operating since December 2011, in which the feed water's solids concentration of 35–150 mg/L is reduced to less than 0.5 mg/L. The system — also available in the North American market through W. Fritz Mezger Inc. (Spartanburg, S.C.; www.mezgerinc.com) — is suitable for both new installations and as a retrofit. For this application, the system removes particles as small as 5 µm (99%), 3 µm (80%) and even 1 µm (35%), says the company.

Water treatment

The recently introduced FoodPro ST line of water-treatment chemicals from GE Power & Water (Trevose, Pa.; www.ge.com) prevents corrosion and scale in stainless-steel sterilizers and pasteurizers in the food and beverage industry, and they are less expensive than alternatives because they contain no molybdate. When calculated on the costs to treat 1 m^3 of water, FoodPro ST chemicals are 30% more

(*Continues on p. 10*)

A new catalyst enables lower-temperature H_2 production using the sulfur-iodine cycle

Among the many different ways being investigated for making hydrogen "from water" is the so-called sulfur-iodine (S-I) cycle, which involves three chemical reactions whose net products are H_2 and O_2: the decomposition of sulfuric acid into SO_2, H_2O and O_2; the decomposition of hydrogen iodide into H_2 and I_2; and the regeneration of H_2SO_4 and HI by the Bunsen reaction ($I_2 + SO_2 + 2H_2O \rightarrow 2HI + H_2SO_4$). Because the S-I cycle requires only water and heat, it has the potential for making H_2 using solar energy as the heat source.

One of the main drawbacks of the S-I cycle (in addition to the use of corrosives materials) is the high temperature (900°C) required for the decomposition of H_2SO_4 — the most energy-intensive step. Up to now, only expensive platinum-based catalysts have been developed to lower the temperatures required for this step in the cycle.

A new catalyst — a macroporous-supported Cu-V oxide — has been developed by professor Masato Machida at Kumamoto University (Kumamoto; www.chem.kumamoto-u.ac.jp/~lab0/machida), in collaboration with Toyota Motor Corp. (Toyota; Tokyo, both Japan),

(*Continues on p. 13*)

Note: For more information, circle the 3-digit number on p. 60, or use the website designation.

Microbial processing of ore

Extraction of metals, such as lithium, from laterite ores is usually carried out through solubilization of metals by acids, such as sulfuric and hydrochloric acids. However, substantial metal recoveries from laterites have been achieved only through thermal pre-treatment of laterites, using high concentrations of acids at high temperatures.

Microbial processing of laterite ores at ambient conditions can reduce acid and energy consumption.

Microbial processing of laterites for nickel extraction has been extensively studied using several acid-producing fungal species. However, there are major drawbacks when using fungi, such as the cost of microbial nutritional substrates required for organic acid production and excess production of microbial biomass with relatively poor yield of metal values.

Now a team from the Institute of Minerals and Materials Technology (www.immt.res.in), and the Regional Center of Central Tuber Crops Research Institute (both Bhubaneswar, India; www.ctcri.org), led by professor Lala Behari Sukla, has successfully extracted nickel through the bacterial reduction of laterite chromite overburden (COB) at Sukinda Valey in the state of Odisha.

The Sukinda Valley is one of the major chromite reservoirs in the world and the only known deposit of nickel in India.

To recover nickel embedded in the goethite [Fe(O)OH] matrix the team used *Acidithiobacillus ferrooxidans*, which reduces the ferric iron in goethite by using elemental sulfur as an electron donor.

The microbial processing experiments showed that up to 41% nickel extraction was achieved, at anoxic condition in 18 days from COB (1% nickel grade) at 5% pulp density.

The process was carried out without any thermal pre-treatment or activation of COB prior to microbial processing.

(Continued from p. 9)

cost-effective than the corrosion inhibitor molybdate, GE says. FoodPro ST products use a blend of organic corrosion inhibitors, phosphates, polymeric dispersants and a wetting agent, and are designed specifically for food sterilization equipment. GE says in tests with its products and alternatives, the FoodPro ST chemicals offered equal or better levels of corrosion and scale inhibition than current molybdate-based products without heavy metals.

CHP & CO_2 capture

GE (Fairfield, Conn.; www.ge.com) recently unveiled the first combined heat and power (CHP) system at a commercial greenhouse. The system captures CO_2 and uses it to feed tomatoes during daylight photosynthesis. The cogeneration system is located in Camarillo, Calif. at the Houweling Tomato greenhouse. It provides 8.7 MW of electrical power and 10.6

(Continues on p. 12)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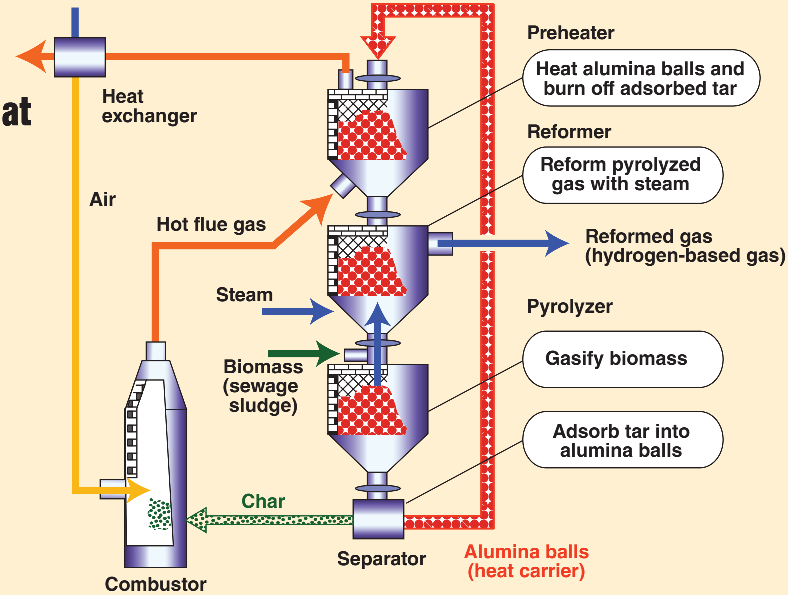
Demonstration for a process that makes H_2 from sewage sludge



Japan Blue Energy Co. (JBEC; Tokyo, Japan; www.jpo-net.co.jp), Daiwa Lease Co., Toyota Tsusho Corp., and Mitsui Chemicals, Inc. have established the Business Research Group of Hydrogen Innovation Town (BRG-HIT) to start verification tests for a new technology for making hydrogen from biomass and sewage sludge. Construction on the world's first biomass-to-H_2 plant began October 2011 at Idex Eco Energy Co. (Izumo, Japan), and the facility will use JBEC's proprietary Blue Tower technology.

Preliminary small-scale experiments have shown that the Blue Tower technology can successfully convert the sewage sludge into an H_2-rich gas. Now, through continuous verification runs at the plant, JBEC and collaborators are expecting to establish the methodology and technology for the commercial production of bio-H_2, and to develop a business model.

Blue Tower (flowsheet) is an entirely new technology that combines pyrolysis and steam reforming. The process features a unique heat-transfer system, whereby heated ceramic balls (heat carriers) are used to supply the energy needed for the pyrolysis and reforming processes, as well as to prevent fouling caused by tar formation. The heat carriers are continuously circulated within three vertically aligned vessels that are the core of the Blue Tower: the pyrolyzer (bottom), the reformer (middle) and the preheater (top). The Blue Tower process runs continuously and completely autonomously without any additional external energy supply.

In the pyrolyzer, biomass (woodchips, sewage sludge and so on) is contacted with high-temperature alumina balls at 550°C to form biogases, such as methane. This biogas is further heated to 950°C by the alumina balls and steam, which reforms the gas into hydrogen. The plant has a capacity of 10 ton/d of biomass (dry) and produces 15,000 Nm^3/d of raw gas and 5,300 Nm^3/d of purified (99.99%) H_2.

The companies plan to introduce Blue-Tower technology to sewage-treatment facilities around the country, which will facilitate the supply of H_2 for both stationary and vehicular fuel cells, and thus contribute to a low-carbon economy.

Quick-charging lithium ion batteries on the horizon

Conventional lithium-ion batteries (LIBs) are unsuitable for high power applications as in electric vehicles, because they take a long time to charge, according to a team from the Interdisciplinary School of Green Energy, of the Ulsan National Institute of Science and Technology (Ulsan, South Korea; www.unist.ac.kr). Now the team, led by professor Jae-phil Cho, found that it can charge an LIB in a few minutes, instead of several hours, by using carbon-coated single-crystal $LiMn_2O_4$ nanoparticle clusters as cathode material.

The primary particles in spinel $LiMn_2O_4$ nanoclusters are coated with a thin carbon layer using sucrose as the carbon source. Sucrose carbonization on the single-crystal particle surface results in the formation of an electrical network within the secondary particle. Using this material in a cell affords an extremely high rate capability as well as a high energy density.

According to the team, the material exhibits a gravimetric energy of 300 Wh per kg of active material (kgm) while delivering a power of 45 kW/kgm and a volumetric energy of 440 Wh per liter of electrode (Le) while delivering 68 kW/Le of power. Using this material would enable an LIB to be charged up to 97% in 100 s and deliver more than 63% of the initial capacity after 2,000 cycles without changing power, at the same charge and discharge rates of about 3 min.

(*Continued from p. 10*)

MW of thermal power. During the combustion process, water vapor is condensed from the exhaust gas and used in the greenhouse operations. CO_2 from the gas-engine exhaust is purified and piped into the greenhouse. The flexible CHP system is capable of providing power to the local electrical utility. The natural-gas-fueled CHP system is ultra-efficient, with a total thermal efficiency of 90%. And because it uses CO_2 and water from the gas exhaust, the efficiency is effectively over 100%, GE says.

Bio-based adipic acid

A Duke University (Durham, N.C.; www.duke.edu) research team that was working on cancer genetics has found a way to alter yeast and bacteria so that they produce an enzyme that could be an important key to a proposed biological-based route to adipic acid from cheap sugars. The team discovered a genetic mutation in cancer cells that could be used to elicit a functional change in a closely related enzyme. The change would convert the enzyme to 2-hydroxyadipate dehydrogenase, which is a critical component in the proposed bio-based route to adipic acid production. The 2-hydroxy adipate dehy-

(*Continues on p. 14*)

Odor control in small doses

A team headed by professor Zhiguo Yuan, from the Advanced Water Management Center, University of Queensland (Brisbane, Australia; www.awmc.uq.edu.au) claims to have developed a new method for corrosion and odor control in sewers that is more cost-effective and environmentally friendly than other chemicals commonly used by the water industry. Corrosion and odor problems are caused by hydrogen sulfide (H_2S) produced by bacteria, which reduce sulfate to sulfide in anaerobic sewers.

The team's method, involving a mix of chemicals called Cloevis, consists of intermittent dosing — 8–24 h/wk dosing or longer, depending on biofilm thickness, previous dosing history, weather and other factors — of mainly nitrite and hydrochloric acid simultaneously, to suppress both sulfide and methane production. Previous strategies require continuous chemical addition, with inevitably high chemical consumption and operational costs, on top of their large environmental footprint.

Earlier research by the team had shown nitrite to be effective in inhibiting sulfide and methane production in sewers. Recently, the team has shown that it is the biocidal effect of free nitrous acid (HNO_2 — formed from nitrite), rather than the nitrite itself, which causes the suppression of sulfide and methane. Also, it has verified that hydrogen peroxide enhances this biocidal effect.

It was clearly seen that bacteria residing in sewer biofilms were killed by exposure to nitrous acid. Simultaneous addition of H_2O_2 and HNO_2 to sewer biofilm increased the killing of the bacteria to up to 99% — much higher than HNO_2 or H_2O_2 alone.

These ground-breaking findings led to the development of an intermittent dosing strategy using laboratory-scale sewer reactors. Dosing parameters (concentrations, pH and exposure time) were optimized through experiments and mathematical modeling.

The strategy has been successfully trialed in full-scale sewers in southeast Queensland for 6 mo. With help from the university's commercial arm, Uniquest, further commercialization activities have been planned and implemented in the U.S. and Canada.

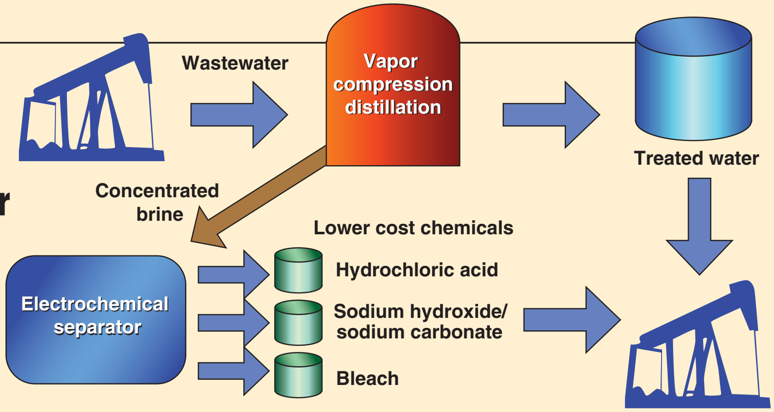
A new catalyst enables lower-temperature H_2 production (*Continued from p. 9*)

that enables the decomposition of H_2SO_4 to occur at 600°C.

The catalyst is prepared by the stepwise impregnation (via a dissolution-precipitation process) of $Cu(NO_3)_2$ and NH_4VO_3 onto a 3D-ordered mesoporous SiO_2 substrate, followed by heating at 650°C. This yields a copper pyrovanadate ($Cu_2V_2O_7$; melting point 780°C) both on the surface and inside the pores of the support. Thermal aging at 800°C causes the congruent melting of $Cu_2V_2O_7$ followed by smooth penetration of the melt into mesopores and homogeneous covering of cavity walls.

The new catalyst system has shown higher reaction activity compared to the existing precious metal system, and also has shown corrosion resistance even under strong acidic condition.

Two technologies combined to treat oil and gas wastewater



A partnership between New Sky Energy (Boulder, Colo.; www.newskyenergy.com) and 212 Resources (Houston, Tex.; www.212resources.com) combines the two companies' technologies to generate freshwater and usable inorganic chemicals from produced water in petroleum and natural-gas drilling operations.

212 Resources has developed a vapor compression distillation process that concentrates brine streams with varying levels of total dissolved solids (TDS) and generates freshwater, which the company calls "engineered water," for re-use in drilling, well completion and oil and gas production. The concentrated brine from 212's process, with up to 300,000 parts-per-million (ppm) TDS, becomes the input feed for New Sky Energy's technology, which involves a proprietary electrochemical reactor and a chemical precipitator. "The New Sky technology efficiently converts highly concentrated brine into useful chemicals," says company CEO Deane Little.

New Sky's reactor separates the salt solution into acid, base, hydrogen and oxygen or chlorine streams (*Chem. Eng.*, June, p. 11). The hydroxide base stream reacts with waste carbon dioxide to produce sodium carbonate and bicarbonate, while chlorine is used to make hydrochloric acid and bleach. In this application, Little says calcium and magnesium ions are removed prior to entering the New Sky reactor, using water softening agents produced by the process.

New Sky's Little says the two companies will start a "commercial pilot" plant in Texas using both technologies in the winter of 2013. "We envision treating water in regional hubs to minimize transportation miles," he explains.

Catalytic ethane-cracking process allows lower-temperature operation

Aither Chemicals LLC (South Charleston, W.Va.; www.aitherchemicals.com) is planning to build a commercial-scale plant based on a catalytic ethane-cracking process that uses 80% less energy and generates 60% less carbon dioxide than conventional steam-cracking of ethane.

The company has refined a mixed metal-oxide catalyst that was originally developed by Union Carbide in the 1980s. The catalyst contains molybdenum, niobium, calcium, vanadium and others that are part of Aither's proprietary technology.

Around the catalyst, Aither has built a streamlined and highly scalable process that Aither CEO Leonard Dolhert says can save money both on the operational side, as well as the capital expenditure side.

"Because the reaction is exothermic and runs at a much lower temperature (350°C) than steam cracking, the energy use is greatly lowered," Dolhert says. On the capital side, the process generates very little co-product, and the only one it does produce — acetic acid — is much easier to separate than the hydrocarbon co-products found in steam-cracking operations.

The demonstration plant uses commercial-scale tube reactors for the catalytic cracking, which makes the scaleup very straightforward, Dolhert says. "You're not changing the size of anything — you're just adding more reactors to get to the commercial-scale plant," he explained.

Aither has demonstrated the ethane-cracking process in its West Virginia facility, and is raising cash for the commercial plant, which Dolhert anticipates will be located in the tri-state area of Ohio, West Virginia and Pennsylvania to take advantage of wet natural gas from the Marcellus shale formation. The plant will be fully operational in three to five years, he forecasts.

Aither plans to sell the ethylene it produces directly, as well as manufacture and sell the ethylene derivatives polyethylene, ethylene oxide and ethylene glycol.

Another advantage to pursuing a commercial-scale catalytic ethane-cracking plant, Dolhert says, is that the facility can easily fit into underutilized chemical sites that are too small for conventional ethane steam-cracking plants. ■

(*Continued from p. 12*)

drogenase has been elusive to researchers, in part because it doesn't exist naturally, says Zach Reitman, one of the Duke scientists working on the project. Adipic acid is an important building block chemical that is used in nylon production, among other areas.

Graphene coating

Researchers at Monash University (Melbourne, Australia; www.monash.edu) and Rice University (Houston; www.rice.edu) have used a chemical vapor deposition technique to apply graphene to a copper metal surface at high temperatures. The graphene coating rendered the copper more corrosion-resistant to salt water by a factor of 100, and was more difficult to damage than polymer coatings. The research team is now investigating ways to apply the graphene coating to metals other than copper, and also ways to coat at lower temperatures, which would simplify production and enhance market potential.

Making MOFs

Chemists at Queen's University Belfast (U.K.; www.qub.ac.uk) have patented a solvent-free process for making metal-organic frameworks (MOFs) porous materials that promise to greatly reduce the production time of these important porous materials. Two inexpensive precursors are simply ground together in a basic milling machine, producing MOFs powder within a few minutes.

Queen's spin-out arm, QUBIS, has formed a new company — MOF Technologies (www.moftechnologies.com) — to exploit the technology. ❏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Biofuels coalition defends Renewable Fuel Standard

A large coalition of advanced and traditional renewable-fuel stakeholders joined forces last month to defend the U.S. Renewable Fuel Standard (RFS) and the economic, employment, and national security benefits they say the RFS provides. The new coalition, Fuels America (Washington, D.C.; www.fuelsamerica.com), spans the full spectrum of domestically grown renewable fuel, national security, renewable energy and other stakeholders.

The launch comes as the Environmental Protection Agency considers a request to "waive" the RFS, a move that coalition members stressed would have serious consequences for America's rural communities, renewable technology innovators and energy independence. Coalition members noted that the advanced renewable-fuel sector has benefited directly from the RFS, with advanced facilities now producing fuel in several states.

OECD CLI forecasts weakening growth, ACC report says . . .

The August composite leading indicator (CLI) from the Organization for Economic Co-operation and Development (OECD; Paris; www.oecd.org) shows that most major world economies will continue to see weakening growth in coming quarters, according to OECD data that were included in the American Chemistry Council's (ACC; Washington, D.C.; www.americanchemistry.com) Weekly Chemistry and Economic Report.

The economies of the U.S. and Japan will likely see moderating growth, while those of Canada, Germany, France, Italy and other areas of Europe will see weak growth, as will those of India and Russia. CLIs for the U.K. and Brazil, however "continue to point to a pick-up in growth," the ACC report says.

"In China, the CLI points to soft growth, but tentative signs are emerging that the recent deterioration in the short-term outlook may have stabilized," the ACC report comments.

EPA SCIENTIFIC ADVISORY PROCESS REFORM BILL INTRODUCED

U.S. House Science, Space and Technology committee members introduced legislation to reform the Environmental Protection Agency's (EPA; Washington, D.C.; www.epa.gov) Science Advisory Board (SAB) and its sub-panels.

The bill (H.R. 6564) is aimed at strengthening public participation, improving the process for selecting expert advisors, expanding transparency requirements and limiting non-scientific policy advice.

Established by Congress in 1978, the SAB plays a critical role in reviewing the scientific foundation of EPA regulatory decisions and advising the Agency broadly on science and technology-related matters.

These provisions draw upon recent recommendations from the Keystone Center's Research Integrity Roundtable, the Bipartisan Policy Center and other stakeholders, as well as relevant testimony received recently by the Committee. ❑

Environmental product impacts addressed in ASTM initiative

ASTM International (West Conshohocken, Pa.; www.astm.org) has launched a new initiative aimed at understanding the real environmental impact of products, from raw material extraction to disposal and recycling.

The ASTM program "will provide scientifically based, quantifiable information about product parameters such as resource consumption and ozone depletion, which will give both businesses and consumers an understanding of a product's real impact on the environment," says Timothy Brooke, vice president of certification, training and proficiency testing at ASTM. Through ASTM's certification program, technical advisory committees will oversee the development process for Product Category Rules (PCRs).

The initiative is a Program Operator for PCRs and Environmental Product Declarations (EPDs), which will provide the venue for developing PCRs and verifying EPDs. PCRs will detail the rules and guidelines for developing environmental declarations for products that can fulfill equivalent functions. EPDs will be verified to ensure their adherence to the ISO 14040 standards, as well as to ensure that lifecycle assessment data accurately describes the environmental aspects of a product.

. . . while leading economic indicator for U.S. suggests sub-par 2013 growth

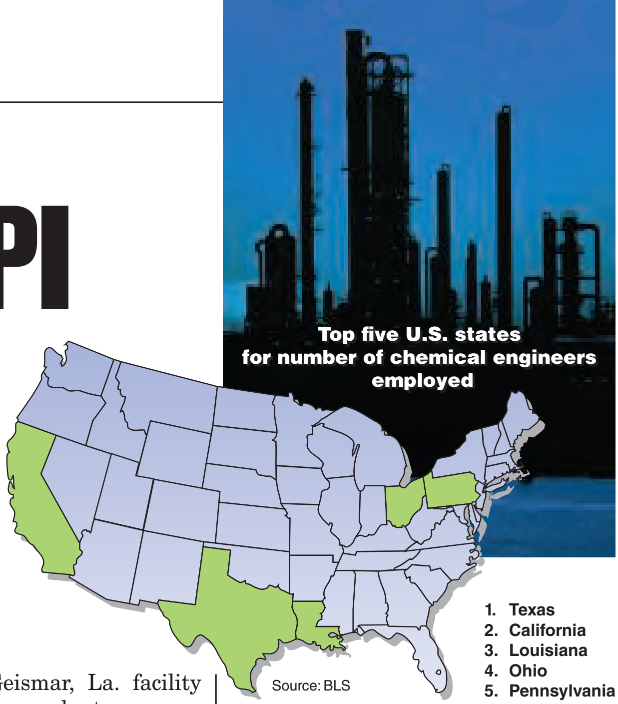
The American Chemistry Council recently released its monthly Chemical Activity Barometer (CAB), a leading economic indicator derived from a composite index of chemical industry activity. The September CAB showed a 0.3% growth over the previous month. This represents the third consecutive monthly increase in the CAB, and follows small upward revisions for the previous three months. "While it is encouraging to see three consecutive months of gains, this is not yet cause for celebration. Rather, what we're seeing is that the CAB is signaling sub-par economic growth into 2013 as the economy continues to face strong headwinds and concerns around the fiscal cliff crystallize," said Kevin Swift, ACC chief economist.

"Interestingly, we are seeing this year's economy repeat the pattern of 2010 and 2011 … just as the first quarter discussion about economic recovery is finally gaining traction, the recovery … disappears."

According to Swift, September's uptick in growth, after three consecutive months of sub-par growth, reveals a trend also witnessed in both 2010 and 2011, where the ACC observed a strong upswing in the fourth quarter of the year, a gradual slowing of growth in the first quarter, followed by consecutive declining months into the third quarter. ■

WANTED: CPI ENGINEERS

Workforce challenges create a competitive labor market for chemical engineers



A number of factors, including plans for new plants and expansions, as well as the retirements of experienced personnel, are creating an especially competitive labor market for engineers and technical workers in the chemical process industries (CPI). The situation is placing upward pressure on salaries for chemical engineers, but continues to challenge companies in the area of knowledge management and workforce development.

"Recruiting chemical engineers continues to be challenging," says Joe McDougall, vice president for human resources at Honeywell's (Morristown, N.J.; www.honeywell.com) Performance Materials and Technologies division. "The chemical and [petroleum] refining expansions in the Gulf Coast region continue to make chemical engineers in high demand."

Many chemical engineers are attracted to the expanding natural gas industry, says Randall Dearth, CEO of Calgon Carbon Corp. (Pittsburgh, Pa.; www.calgoncarbon.com) and former head of Lanxess Corp. (Pittsburgh, Pa.; www.lanxess.com). In the Northeast U.S., where natural gas from shale deposits continues to impact the CPI, along with other industry sectors (see *Chem. Eng*., October 2012, p. 17), a competitive labor market also exists. Dearth says there is definitely a shortage of chemical engineers in the Pittsburgh area, and the hiring climate is very competitive.

Tom Yura, senior vice president at BASF SE (Ludwigshafen, Germany; www.basf.com) and site manager for the company's Geismar, La. facility and Jim Armstrong, plant manager for the Rhodia (Lyon, France; www.rhodia.com) facility in nearby Baton Rouge, La., have observed a similar competitive environment for engineering workers. "We're seeing strong competition for chemical engineering graduates in the Baton Rouge area, and earlier recruitment by companies of chemical engineers coming out of local universities," Yura says.

Recruiters perspective

Chemical industry recruiters, such as Allan Berman, Jim Terkovitch and Jessalyn Cotter of Engineering Resource Group (Morris Plains, N.J.; www.engineeringresource.com) and Patrick Ropella, CEO of the Ropella Group (Milton, Fla.; www.ropella.com), say that although the demand is strong for chemical engineers, the hiring climate is stable from a volume standpoint, not significantly more or less active than last year in most areas and for most job functions.

"We've seen a decent rise in permanent staffing," Berman says, "which could indicate a degree of confidence about the future of the economy."

Ropella outlined some of the areas that are particularly active in searching for new engineers. Companies that make chemicals for hydraulic fracturing are expanding capacity and plants, and need engineers, for example, as are companies that make batteries and equipment for large-scale grid-energy storage. "Renewable energy in general — batteries, solar and wind energy — is a hot area," Ropella says.

Experience and skills needed

Although job prospects are generally good for chemical engineers at all experience levels, those with significant industry experience are at even more of a premium. "Emerging regions are graduating chemical engineers at higher rates, but finding the necessary industry experience remains a challenge," says Honeywell's McDougall.

For the past ten months, the uncertainty in the global economy has made it somewhat more difficult to attract working engineers away from their current employers. Workers are less likely to take a chance on a new company, McDougall says.

With a range of advanced technologies, Honeywell has had a challenging time finding the right skill sets for its jobs. "It takes a disciplined hiring process to find viable candidates with skills that are close to our needs," says McDougall, "as well as flexible hiring managers who are willing to develop those foundational skills into the ones we really need."

In terms of experience levels, those in the range of about six to 15 years are in the highest demand, says Ed Evans, executive vice president and chief human resoures officer at global chemical distributor Univar (Redmond, Wash.; www.univarusa.com), a figure corroborated by Rhodia's Armstrong. While Armstrong says the availability of early-career candidates appears adequate and the number with a lot of experience is also good, "There seems to be somewhat of a gap in chemical engineering candidates in the six- to 15-year experience range."

The gap has made experienced professionals very difficult to find and expensive when you do find someone, Armstrong comments. "We hired a chemical engineer in March of this year after a year-long search. We were looking for five to ten years of experience and found it very difficult to find someone in that range with plant experience," he explains.

The number of plant expansions and other planned projects is focusing attention not only on chemical engineers, but on other technically skilled workers in the CPI. The shortage of chemical plant operators, welders, pipefitters and other skilled technical workers is a challenge in sectors well beyond the chemical industry, but its effects on the CPI are significant. Numerous studies, including one in 2011 called the Skills Gap Report, by the non-partisan think-tank known as the Manufacturing Institute (MI; Washington, D.C.; www.themanufacturinginstitute.org), indicate that 80% of manufacturers in the U.S. are experiencing a shortage in skilled production talent, such as machinists, maintenance technicians and chemical process operators, while 60% are experiencing a shortage of engineers.

The importance of the skilled worker shortage is amplified by the significant amount of planned expansion projects, according to BASF's Yura. He explains that the billions of dollars in projects planned are likely to have overlapping timelines, and if projects are on the same timeline, they are all going to need the same type of workers at similar times.

Construction contractors are going to have challenges to find the right people, like welders, pipefitters and others, Yura says, "and if we can't find sustainable workforce scenarios, projects are going to be delayed and overbudget, or quality could suffer."

SALARIES AND PROJECTIONS

The competitive labor market and minimal unemployment for chemical engineers is keeping salaries high in general. An informal survey of over 500 *Chemical Engineering* subscribers in North America and Europe this October showed an average annual salary of about $108,000 for all experience ranges and for all industry sectors.

U.S. Bureau of Labor Statistics (BLS; Washington, D.C.; www.bls.gov) data from 2011 (the most recent available) reveal a salary gradient that depends on the particular industry sector (see Table 1).

Alan Lacy, a supervisory economist with BLS who is involved with producing the Occupational Outlook Handbooks (including the one for chemical engineers) that his agency generates every two years for specific jobs, explains that BLS data indicate that although there will be some increased use of chemical engineers in R&D related to developments in biotechnology and biomedical science, employment growth for chemical engineers will be driven primarily by industry growth.

Therefore, despite demand for chemical engineers, the BLS projections suggest employment of chemical engineers in the U.S. will grow by 6% by 2020, which is slower than the total for all engineers (11%), and the total for all occupations (14%). BLS methodology projects 10 years ahead every two years, but does not make short-term interim projections.

Within the industrial chemical sector, employment of chemical engineers is projected to grow by 21% in plastics manufacturing and 13.4% in oil and gas extraction by 2020. Self-employed chemical engineers will grow by 18.8% by 2020. Chemical engineers working in nonmetallic mineral production are projected to grow by 10% by 2020, while those in fabricated metal product production will grow 12.5%. Chemical engineers in educational services will grow by 15%, and those in professional, scientific and technical services (28%). Offsetting those faster growth rates are the declining number of chemical engineers projected to be working in chemical manufacturing (–11%), as well as machinery (–4%) and computer and electronic equipment manufacturing (–19%).

For petroleum engineers in oil and gas extraction, the total is projected to grow 25.6% and mining support by 9.9%.

Within the chemical manufacturing sector, the fastest growth rate of any type of engineer is projected to be biomedical engineers, with a 50% gain in employment expected by 2020. Across all fields, the number of biomedical engineers is expected to grow by 60% in terms of numbers employed, by 2020.

For other engineering types, the number of civil engineers is projected to grow by 19.4% by 2020, while agricultural engineers (9.1%), environmental engineers (20.7%), electrical and electronics engineers (7%), petroleum engineers (17%), mechanical engineers (8.8%), industrial engineers (6.4%), and health and safety engineers (13.4%) are all projected to grow in number by 2020, according to the BLS data. ❑

Educational initiatives

Because the problem of the skills gap is complex, the solution is likely to be as well. Companies need to work with contractors to ensure people are available to execute the work, Yura points out. Improved workforce forecasts would help, he adds, because companies could decide to position themselves differently to avoid worker shortages.

The MI, a nonprofit affiliate of the National Association of Manufacturing (NAM; Washington, D.C.; www.nam.org), has also launched an initiative aimed at training some of those future technical employees to fill the gap. Partnering with the Society of Chemical Manufacturers & Affiliates (Socma; Washington, D.C.; www.socma.com) and others, MI is working to expand NAM's Manufacturing Skills Certification System, which is being used to integrate nationally portable, industry-recognized learning standards and content into high school, community college and university programs to develop technically skilled workers.

By bringing together industry leaders and schools the MI-Socma partnership aims to award a rapidly increasing number of certifications for jobs in welding, machining, metal-forming and maintenance, says Lawrence Sloan, Socma's president and CEO. The program leverages existing certification programs and curricula developed by industry and loops in community colleges to teach those courses, explains Sloan. The program began with four schools only three years ago, but now has expanded to more than 100 community colleges in different areas, he says. Sloan cited one example of the rapidly expanding efforts of the NAM-Endorsed Manufacturing Skills Certification System. Last year, the Institute and its partners made a commitment with President Obama to reach 500,000 certifications by 2016. In 2011, it was announced that over 84,000 certifications were issued.

Calgon Carbon CEO Dearth commends the NAM model, and says the involvement of technical schools and community colleges will be critical to addressing the shortage of chemical plant operators and other skilled technicians that the CPI is facing.

For workers in the petroleum and

Top five U.S. states
for average chemical engineering salary

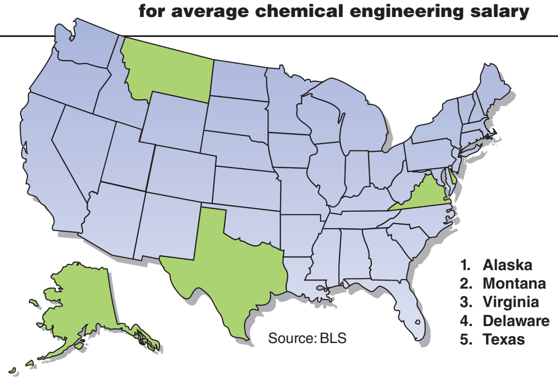


TABLE 1. MEAN SALARIES FOR U.S. CHEMICAL ENGINEERS BY INDUSTRY SECTOR.

Basic chemical manufacturing	$99,440
R&D services	$104,140
Resins, synthetic rubber and artificial fibers	$91,610
Petroleum and coal products	$104,040
Paints, coatings and adhesives	$91,930
Natural gas distribution	$157,940
Support services for mining	$141,320
Company management	$130,250
Hardware and supplies merchant wholesaler	$125,340
Scientific and technical consulting services	$114,550
Overall	$99,500

Source BLS data from 2011

natural gas industries, the American Petroleum Institute (API; Washington, D.C.; www.api.org) recently launched an initiative with the University of Phoenix (Phoenix, Ariz.; www.phoenix.edu) to help meet the rising demand for experienced workers by helping to develop a pipeline of skilled employees for the energy industry. "The oil-and-gas industry will need a new generation of highly skilled employees to safely develop our country's energy resources," says API president and CEO Jack Gerard. API has coordinated with industry leaders to provide information to the University of Phoenix to help identify where the oil and gas industry could benefit from additional training and education.

Retirement is a larger factor

Aside from new capacity, another factor driving the competitive labor market for engineers is the replacement hiring needed to keep up with retiring engineers. Engineers in the "Baby Boom" generation — the leading edge of which is reaching retirement age now — had been staying on the job longer over the last few years because of the effects of the economic recession. With the stock market recovering most of the equity lost during the recession, that barrier is not as severe anymore.

Nearly half of chemical workers are nearing retirement age, and will be leaving the workforce over the next decade, Dearth says. We have to find a way make sure there is a pipeline of students interested in science, engineering and math, he adds.

"Replacing an aging workforce, particularly in the hourly ranks is a significant workforce challenge," says Rhodia's Armstrong. "In the next three to five years, I will lose a significant portion of my plant population due to retirement. This is not easily replaced."

As personnel leave companies, they do so with valuable experience that companies are trying to capture. "There's a general industry trend toward younger workers with lower levels of experience," Yura says, "and that introduces new risk factors."

Knowledge management

Knowledge management, or the ability to retain company know-how and experience and expertise despite worker turnover, is becoming more important as retirement rates are poised to pick up over the next five to ten years.

The challenges posed by knowledge management and transfer have been evident for some time in the CPI, but the attention on the issue has never been higher, and the tools and strategies available never more accessible.

"Information transfer at the time of retirement is too late," BASF's Yura says. His company's core principle is to establish an institutionalized knowledge-management program, and set up dedicated systems for information technology, performance reviews, documentation, and others, as they relate to knowledge management.

Other methods include retaining retirees as part-time workers, or as mentors for younger engineers. Such is the case at Rhodia's Baton Rouge site, according to Armstrong. Also, early hiring incentives can create more overlap between retiring people and their less experienced replacements.

Dearth, from Calgon Carbon, says his company is establishing mentor programs between older and younger engineers. Also, the company is enticing people to return to work in a consultant capacity after their retirement to help transition existing engineers to new roles.

Honeywell's McDougall says that in many areas, his company has experts with extraordinary depth in their field and replacing that knowledge will always be a challenge for Honeywell. "A sound and ongoing to business practice for us is to take steps to ensure that key technologies do not rely on a single person," McDougall says. "We focus on single points of failure — those places where just one or two employees understand a process or technology — and then work with those employees to document their knowledge using the most effective and practical approach." For example, job shadowing may work in some instances, while formal, written documentation fits other situations, he explains.

Job mapping

To help facilitate knowledge management, make training more effective, as well as help employees visualize their career path, a method developed by Sai Ranade, of RWD Technologies LLC (Houston; www.rwd.com) may be a useful tool (see *Chem. Eng.*, April 2011, p. 54–58).

Known as a competency-mapping framework, the method systematically creates grids showing the minimum levels of cognitive competencies, or knowledge, required to qualify a person for a task, as well as other functional skills that allow the person to excel.

"Many companies have not specified their own jobs," Ranade says, explaining that his method for visualizing job tasks came out of a consulting arrangement with Ecopetrol S.A. (Bogota, Columbia; www.ecopetrol.com). Ranade's method presents a universal, visually based framework for job analysis, and provides a method for establishing clear relationships between job tasks, training and career paths.

Among other things, the framework method "offers a path to standardize training, thus saving time and money," Ranade says, because "learning interventions become more targeted." The model can help companies identify the specific job functions that bring value to the company. ■

Scott Jenkins

UNDER PRESSURE

Today's pressure measurement devices are improving, so your process can, too

Crystal Engineering

Honeywell

FIGURE 1. (left). With enhanced performance, modular construction, and advanced display and integration features used with Experion PKS, the SmartLine measurement system helps processors reduce costs, avoid unplanned downtime, improve product quality, reduce spare parts inventory and shorten time to repair, says the company

FIGURE 2. The nVision from Crystal Engineering is a reference-class recording device that delivers high-speed recording capability and can be used as a troubleshooting device to aid in efficiency and maintenance

For every chemical process there are different pressure measurement requirements. Some demand devices that are compatible with a unique chemistry, others require pressure instrumentation that won't pose a risk to workers or processes and many call for instruments that can handle a wide temperature range. However, throughout the chemical process industries (CPI), there are a few items on everyone's pressure measurement wish list. It seems all processors want to improve the overall efficiency of the process, all desire devices that are better able to record and communicate information, and all need more stability from their instruments. Fortunately, instrumentation providers are developing new products that meet these needs.

Improving efficiency

"In today's environment, helping facilities is about helping them do more with less," says Ted Dimm, product line manager for pressure, with Honeywell (Morristown, N.J.; www.honeywell.com). "Every facility has fewer people, especially in their maintenance departments. And following the loss of skill sets as older people retire and younger replacements lack the knowledge, they become more reliant upon instrument and equipment manufacturers to make life simpler for them. And pressure measurement instrumentation is an area where we can help."

Dimm says Honeywell strove to add features to its SmartLine pressure-measurement devices that would allow both operation and maintenance professionals to become more efficient. With previous, existing HART-enabled pressure-measurement instruments, it was possible to send 32-character messages to the transmitter, which were planted in the transmitter memory. This allowed maintenance people to use a handheld device to read that message. "But, it's a lot of work to hook all that up, so we added some advanced display technology, which allows the transmitter to have the message in its memory, but also to post that message in the transmitter's display, so a handheld device is no longer needed."

Operators can now send a message to the transmitter to be displayed on the indicator, where the maintenance technician will see the message, know that he has the right transmitter without checking the tag and, if the message is comprehensive, he will know which tasks — such as calibration — he is expected to perform without using a handheld device. "This saves a lot of time with respect to communica-

FIGURE 3. Brooks SolidSense II ATEX industrial pressure transmitters use glass-fused strain gauge technology, which enables high performance in industrial applications

tion back and forth with operations for additional directions," explains Dimm.

A maintenance mode indication was also added to the SmartLine devices. When used in conjunction with Honeywell's Experion PKS (Figure 1), both operators and the network can advise the transmitter when the loop is in a mode that is safe for maintenance. "This means in addition to knowing that it's the right instrument and what actions he should take, he also knows whether the transmitter is available for maintenance," says Dimm. "The combined display technology and maintenance-mode indication features eliminate tripping alarms and increase efficiency and maintenance safety, as well as the efficiency and safety of the entire plant."

Record keeping

Following tougher regulations regarding the documentation of mandatory safety tests, processors — especially those in the oil and gas industry — are seeking pressure measurement instrumentation that makes it easier to record and document actions.

In the past, standard chart recorders might have been used, but because they are mechanical devices, it is not easy to get recorded information into an electronic format that can be easily emailed or electronically delivered from one place to another.

So, Crystal Engineering (San Luis Obispo, Calif.; www.crystalengineeroing.net) developed the nVision, reference pressure recorder (Figure 2). "This is a reference-class recording device, meaning it provides high-accuracy readings, that delivers high-speed recording capability and can be used as a troubleshooting device to aid in efficiency and maintenance," says Jim Pronge, sales manager with Crystal Engineering.

The device is portable enough to allow complete calibration anywhere and is accurate enough to replace a deadweight tester. This is a gage/absolute pressure datalogger to 15,000 psi and offers differential pressure with up to 0.025% of reading accuracy. And, it displays live data graphically without a PC, but can connect to a PC to view live readings or export tamper-proof digital recordings.

Accuracy and stability

Pressure transmitters are widely used in high-purity and ultra-high-purity fluid storage and delivery systems. Unfortunately, a number of current transducers rely on technologies that have problems with zero and span drift, thermal shift and case stress. Adjusting the pressure transmitter to rectify errors requires ongoing maintenance that increases downtime and cost of ownership. However, a combination of optimum design and materials can improve both signal stability and reliability, says Ken Tinsley, director of pressure and vacuum measurement with Brooks Instrument (Hatfield, Pa.; www.brooksinstrument.com).

For example, Brooks' SolidSense II industrial pressure transmitters (Figure 3) use glass-fused strain gauge technology, which enables a new level of performance. The micromachined strain gauges are matched and fused to the metal diaphragm at high temperature to relieve manufacturing-induced stress. This process reduces drift or lack of zero stability commonly associated with most pressure transmitters.

And the XacTorr CMS capacitance manometers for process vacuum measurement include premium, heated gauges that use dual-zone heating to ensure temperature uniformity. The device's electronics are temperature compensated to minimize drift due to ambient temperature changes.

An important benefit of this manometer is its Mark-IV sensor, which has a chamber that contains surface areas that are not used in pressure measurement. These surfaces provide locations for particles and condensable vapors to accumulate without affecting the sensor, reducing the need for re-zeroing and extending sensor life.❏

PRESSURE MEASUREMENT PRODUCTS

Smart barrel transmitter provides small footprint

Used for shale oil-and-gas applications, the TX200H HART smart pressure transmitter provides a small footprint. Using the latest HART 7 specifications, it reliably communicates asset management data while providing simplified field adjustment. A flexible 10:1 turndown on the pressure ranges from 0 to 15 psi up to 0 to 25,000 psi and allows the transmitters to be ranged as needed to meet user requirements. The transmitter is constructed of 316 stainless steel, welded and hermetically sealed to meet enclosure type 4X and IP66 requirements. It can be mounted directly onto the process or panel mounted within the control panel. — *United Electric Controls Co., Watertown, Mass.*
www.ueonline.com

This pressure indicator offers precision and stability

The PACE 1000 pressure indicator, modular pressure instrument for rack mounting, test bench or bench top applications is available in three grades of precision performance, and a choice

Ashcrof

of pressure ranges (pneumatic and hydraulic) and features internal data logging as standard. Pressure ranges are available up to 14,500 psi, and up to three individual channels can be displayed on the high-resolution touch screen. An icon menu simplifies set up of controller parameters, and connectivity via RS232, IEEE, Ethernet and USB provide for easy PC and peripherals connection, as well as the use of setup software and diagnostics downloads for technical support. — *GE Measurement & Control Solutions, Billerica, Mass.*
www.ge-mcs.com

Pressure transducers meet OEM requirements

Custom design modifications and evaluation services (photo) are available for specialized OEM pressure transducer requirements. Fittings, outputs, enclosures, calibration and mounting methods can be modified. In addition, lifecycle, environmental, shock and other forms of testing can be performed to specifications in a test facility. — *Ashcroft, Inc., Stratford, Conn.*
www.ashcroft.com

This hygienic transmitter has absolute and gage pressures

Cerabar M PMC51 and PMP51 pressure transmitters (photo) are suitable for accurate absolute and gage pressure measurements in gases, steams or liquids and for level, volume or mass measurements in liquids. Standard accuracy is 0.15% with 0.075% accuracy available as an option. Long-term stability is 0.1% of URL/year and 0.25% of URL/five years. The transmitters are available with ceramic or metal process-isolating diaphragm seals, which allow the sensors to work in temperatures up to 752°F or pressures up to 6,000 psi. — *Endress + Hauser Inc., Greenwood, Ind.*
www.endress.com

Omega Engineering

Pressure gage offers metric fittings and ranges

The DPGM409 (photo) covers the full spectrum in pressure measurement with gage, sealed gage, absolute, compound gage, vacuum and barometric pressure ranges. Its core is a stable micro-machined silicon sensor with 0.08% accuracy. Each unit is supplied with a five-point NIST traceable calibration certificate and is tested to industrial CE standards. A user-selectable analog output of 0–5 V d.c., 0–10 V d.c. or 4–20 mA is standard on all models and a built-in wireless transmitter option is also available. — *Omega Engineering, Stamford, Conn.*
www.omega.com

Endress + Hauser

A digital pressure gage with simplified setup

The IP65 rated indoor/outdoor PG10 digital pressure gage features a 5.5-in. display casing, a full five-digit display and a 270-deg. digital dial or radial bar graph that shows a user-selectable pressure range from 0 to 100%. Standard features include tare, peak hold and maximum and minimum ratings, as well as user-selectable units of measure and an auto-off timer. Options include two solid-state relays or SPDT (single pole, double throw) mechanical relay outputs for basic to semi-advanced automation. The gage has an operating temperature range from 6 to 160°F and features pressure ranges from vacuum to 500 psi or 0 to 10,000 psi. — *Automation Products Group, Inc., Logan, Utah*
www.apgsensors.com ■

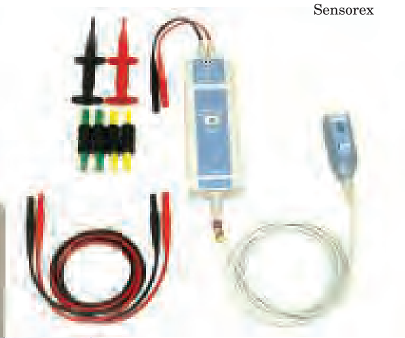
Joy LePree

Fluid Components International

Sensorex

FOCUS ON
Analyzers

JM Science



Yokogawa

Quantachrome Instruments

This flow monitor now has FM and FMc approvals

The Model FS10A Analyzer Flow Switch and Monitor (photo) recently received FM and FMc (Canadian) approvals. The approvals signify that the FS10A is suitable for continuous-flow verification applications that support process-analyzer sampling systems operating in hazardous plant areas in the U.S., Canada and elsewhere. The FS10A's advanced electronics and thermal-dispersion flow-sensing technology features a precision flow sensor element with no moving parts to foul or clog. The sensor element helps ensure continuous reliability with minimal maintenance. The instrument can continuously verify flows within liquid or gas process-analyzer sampling systems. The small and lightweight instrument also features superior low-flow sensitivity, the company says, and has no cavities or dead-legs to trap fluids and lead to contaminated samples. — *Fluid Components International, San Marcos, Calif.*
www.fluidcomponents.com

Measure gas adsorption and desorption with this device

The iSorb-HP (photo) is an automated benchtop device that measures high-pressure adsorption, absorption and desorption of gases, such as hydrogen, carbon dioxide and methane on solid samples. It is useful for determining the specific sorption capacity of solids for a particular gas at high pressures and temperatures. The device can be used in the development of hydrogen storage materials, greehouse-gas capture technologies and other environmental or energy projects. The iSorb-HP is computer-controlled and can measure sorption isotherms at pressures up to 200 bars and temperatures up to 400°C. — *Quantachrome Instruments, Boynton Beach, Fla.*
www.quantachrome.com

Save money on reagents with this titrator

The Aquacounter Karl Fischer Coulometric Titrator, model AQ-2200S (photo), is a high-end titrator designed for determining trace-levels of water. The titrator has three types of electrolytic cells available, including a standard-volume cell and a one-room cell that requires only 25 mL of anode solution. This is helpful in cutting back on the cost of expensive Karl Fischer titration reagents, the company says, as well as reducing hazardous waste. The AQ-2200S allows two titration stations to run parallel with various coulometric/volumetric combinations. With both a coulometric and volumetric channel, users can measure moisture over the entire range from 1 ppm to 100%, or users can double the sample throughput with two identical Karl Fischer titration stations. The titrator has several new enhancements, including a color touchscreen, larger memory capacity and a built-in printer. — *JM Science, Inc., Grand Island, N.Y.*
www.jmscience.com

Use your Apple iPhone to measure pH

This company has developed the first mobile phone accessory for industrial pH measurements. It eliminates the need for dedicated pH meters. Compatible with Apple iPod, iPhone and iPad devices, the PH-1 pH meter (photo) ac-

Note: For more information, circle the 3-digit number on p. 60, or use the website designation.

Casella USA

Emerson Process Management

cessory plugs into the standard Apple dock connector and uses a pH electrode from this company to measure pH to accuracies of 0.1 pH units. The free pH monitoring app displays pH value, millivolts, ambient temperature and solution temperature in realtime. Since it is powered by the Apple device, the PH-1 requires no supplemental energy source. It can measure pH from 0 to 14 and in ambient temperatures from 0 to 40°C and solution temperatures of 0 to 100°C. — *Sensorex Inc., Garden Grove, Calif.*
www.sensorex.com

Make high-voltage oscilloscope measurements with this probe
A new high-speed differential probe from this company can make high-voltage oscilloscope measurements for testing devices such as motors, power supplies and inverters. The model 701927 (photo, p. 23) has a 3 dB bandwidth of d.c. electricity to 150 MHz, and can measure differential or common-mode voltages up to ±1,400 V (d.c. plus a.c. peak) or 1,000 V RMS (root mean square). For ease of use, the compact unit features automatic attenuation detection and obtains its power from the company's probe interface. A 1-m long extension cable allows the probe to be used in thermostatic chambers and for measurements on large or hot devices, and comes as standard equipment. — *Yokogawa Corp. of America, Newnan, Ga.*
www.us.yokogawa.com

This handheld particulate monitor has a high selectivity range
The Microdust Pro airborne particulate-matter monitor (photo) is a portable, handheld instrument that assesses concentrations of suspended matter in a sensitivity range of 1 µg/m^3 to 2,500 mg/m^3. The wide range makes it one of the most versatile monitors on the market, the company says, adding that it is the first instrument capable of graphically presenting variations in dust concentration on a realtime scrolling graph on its LCD screen. This eliminates the need to analyze results on a PC. The Microdust Pro is suitable for industrial hygiene, indoor air quality and workplace exposure investigations. Using near-forward light scattering technology, the instrument can monitor airborne particles like dust, soot, mold spores, smoke and liquid droplets. The Microdust Pro has an internal data logger capable of storing up to 15,700 data points over 32 separate runs. — *Casella USA, Amherst, N.H.*
www.casellausa.com

Find the density of slurries with this device
The DM3 is an inline, continuous density meter that is designed as an alternative to older technologies for determining the density of process slurries. The DM3 calculates density by measuring direct mass over a known volume within a flow tube. By directly calculating density, rather than inferring or estimating, the technology improves accuracy and environmental viability of sensor and mass flow systems, the company says. Data from the company suggest that the DM3 is safer and more cost-effective than nuclear techniques and autosampling in slurry processing. The instrument is suitable in several industries, including water and wastewater, paper manufacturing, power, oil, food-and-beverage and hydraulic fracturing. The DM3 has a highly resilient gum-rubber lined flow tube that stands up to abrasive media. — *Sciam Worldwide, Orlando, Fla.*
www.sciamworldwide.com

This vibration analyzer is safe for hazardous areas
The CSI 2125-IS Machinery Health Analyzer (photo) is an intrinsically safe vibration analyzer that is certified for use in IEC Ex and ATEX Zone 0 and Zone 1 hazardous areas. The CSI 2125-IS allows users to access predictive diagnostics from hazardous areas of their operation, and helps them make better decisions around machinery health for their entire plant, without compromising safety. The CSI 2125-IS delivers route-vibration-analysis capabilities similar to this company's existing machinery health analyzers, including its PeakVue technology, which provides early indication of bearing and gearbox wear. The CSI 2125-IS is compact, lighweight, can operate continuously for up to eight hours, and features a touchscreen for easy use in the field. — *Emerson Process Management, Austin, Tex.*
www.emersonprocess.com

An oxygen sensor for fluegas
The 4OXeco LP sensor uses this company's established lead-free toxic-gas sensor technology to analyze fluegas in power plants and industrial facilities. It is designed to improve accuracy, operational life and resistance to cross-contamination. The 4OXeco LP is a low-power version of this company's existing 4 Series units, for use in measuring oxygen and carbon monoxide content in boiler fluegas. The use of natural gas, LPG, light and heavy oils, biomass, wood pellets, coal and propane in fixed boilers and power plants has increased the amount and variety of contaminants likely to be present in fluegases, the company says, creating the potential for higher incidences of false readings during measurements. — *City Technology, Des Plaines, Ill.*
www.citytech.com ■

Scott Jenkins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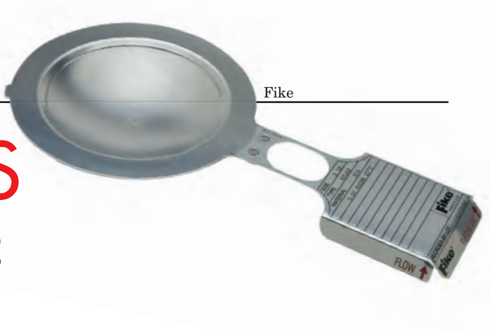
ChemInnovations 2012 Conference & Expo


Fike

ChemInnovations 2012, an educational conference and exhibition tailored for engineers working in the chemical process industries (CPI), will take place at the Ernest Morial Convention Center in New Orleans, La. November 14–15. In addition to a five-track conference program, an awards banquet and the Chementator Lightning Round (see *Chem. Eng.*, October p. 24D-1), the event will feature exhibits from over 160 vendors, who are slated to showcase their latest equipment on the show floor.

The following descriptions represent a small sample of the products and services that will be on display in New Orleans.


Arkema


PBM


seepex

These valves are available in a variety of alloys

This company's double block-and-bleed valves (photo) are custom engineered from standard components in a variety of alloys and pressure classifications according to user specifications. The valves offer full supporting material and testing documentation. Designed for petrochemical and petroleum refining applications where safety and reliability are critical, the valves are available in stainless steel, carbon steel, duplex and exotic materials. The valve connections can be flanged-end, or either female or male national pipe-thread (FNPT, MNPT) connections. Booth 2223 — *PBM, Inc., Irwin, Pa.*
www.pbmvalve.com

Foam PVDF resin with this technology

This company is offering new foaming technology for polyvinylidene fluoride (PVDF) resin that uses a foam concentrate designed specifically to work with Kynar resins in wire- and cable-jacketing applications (photo). Foamed samples utilizing this technology show improved properties, such as thermal and acoustic insulation, reduced shrinkback in the fiber, flexibility, stripability, ease of cutting and others, the company says. The foaming technology results in a closed-cell foam structure that maintains the chemical and temperature resistance of Kynar resins. The technology is targeted at a number of markets, including plenum wire, cable and fiber-optic jacketing, as well as tubes, sheet films and injection molding applications. Foamed articles are easily weldable to other foamed and unfoamed Kynar products. Booth 2631 — *Arkema Inc., King of Prussia, Pa.*
www.arkema.com

These rupture discs have higher pressure capability

The Atlas line of rupture discs (photo) is manufactured using this company's G2 technology for making rupture discs. The patented technology is capable of making rupture discs without the use of hard-score tooling. The process builds rupture discs that are free of stress zones that can fatigue, the company says. The Atlas line matches the characteristics of the company's other product lines with G2 technology. These benefits include a 95% operating ratio, the ability to perform with liquids or vapors, back-pressure resistance and excellent cycling capability. The Atlas series offers higher pressure capability than was previously available, the company says, so the range of pressures that can be handled by products with G2 technology is extended. Booth 2407 — *Fike Inc., Blue Springs, Mo.*
www.fike.com

Chemical dosing in a single skid-based unit

Pre-engineered liquid-chemical-metering systems (photo) from this company can be used in a wide variety of chemical-dosing and water-treatment

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

North American Dismantling

applications. The customizable skid system features high-quality progressive cavity pumps for dosing. With low operating costs and a long service life, the pumps ensure precise metering without pulsation or vapor lock, and are protected from dry-run and overpressure, the company says. The chemical dosing systems are designed to accommodate flowrates up to 100 gal/h and pressure capabilities up to 350 psi. The skid system's components include calibration column, pressure gage, pressure switches and flowmeters. The materials of construction for the components are custom-designed according to the requirements of the user's application. An integrated vector drive with automatic or manual speed control comes standard, eliminating the need for a local interface or control panel. Booth 2130 — *Seepex GmbH, Bottrop, Germany*
www.seepex.com

This VOC-abatement technology uses cryogenics

The Cryo-Condap system (photo) is based on this company's proprietary cryogenic technology for the recovery and abatement of volatile organic compounds (VOCs). The system uses liquid nitrogen and a combination of condensation technologies (including mechanical refrigeration, indirect cooling with nitrogen, direct injection of liquid nitrogen and membranes) to condense and freeze VOC vapors, which are then removed from the process as condensate and frozen particles. The clean process-gas stream will conform to environmental regulations for VOC emissions, the company says. The Cryo-Condap system can recover almost 100% of most solvents, enabling their reuse in the process. Also, the liquid nitrogen is vaporized into nitrogen gas, which can be reused for purging or blanketing. Cryo-Condap systems can treat multiple solvents in one gas stream, and each system is designed to meet specific site and process requirements. Booth 2435 — *Air Products, Inc., Allentown, Pa.*
www.airproducts.com

Industrial demolition and strip-out services provided

This demolition contractor provides a range of industrial demolitions and dismantling services in the U.S. and Canada. The company offers total demolition, selective demolition, industrial strip-out, site-clearing and excavation, tank removal and other related services. Outfitted with the latest demolition and dismantling equipment, the company performs all demolition with its own workers, and strives to implement innovative techniques and methods to save its clients time and money. Booth 2301 — *North American Dismantling Corp., Lapeer, Mich.*
www.nadc1.com

This company offers toll-screening services

This company has moved to a new facility (photo) that has greatly increased its capacities for toll screening. The facility offers seven double-capacity tolling bays and three laboratories that can separate all quantities of material on several of the company's screeners. The technology of the screeners at the facility, along with the expertise of the technicians, allows the facility to separate complex materials, such as very fine powders, sticky products, delicate agglomerates and high-cost raw materials. The new facility includes a larger parts inventory and machine shop, as well as an enhanced screen-making area. Booth 2201 — *Virto/Elcan Industries, Tuckahoe, N.Y.*
www.virto-elcan.com
www.virto-minox.com

These conveyers have specially bonded rubber V-ropes

This company has developed a specialized process for attaching rubber V-ropes to the bottom of stainless-steel cooling and processing conveyer belts that prevents the V-rope from detaching. Most stainless steel belt conveyers in use in the chemical process industries (CPI) have rubber V-ropes on their underside to assure proper tracking. Conventionally, the rubber is hot-bonded to the conveyer belt, but V-ropes can come loose and result in improper belt tracking. This company has developed a V-rope-attachment technique that creates a chemical bond between the rubber and the metal, resulting in superb resistance to chemical and mechanical stresses, as well as high temperatures, the company says. Booth 2422 — *Contibelt Systems Inc., Strongsville, Ohio*
www.contibelt.com

Air Products

Virto/Elcan Industries

Intensify processes with this reactor

This company's Loop Reactor has recently been adapted to continuous processing systems, and can shorten reaction times, reduce byproduct formation and cut operational costs in both new plants and modified existing ones. Engineers from the company have made significant improvements to the reactor to optimize continuous reactions. The Loop Reactor allows the highest possible mass-transfer rates, and can reduce overall consumption of utilities and raw materials. This company offers pilot testing to potential users, so that the industrial plants designed from the pilot unit can have guaranteed performance. Booth 2325 — *Buss ChemTech AG, Pratteln, Switzerland*
www.buss-ct.com

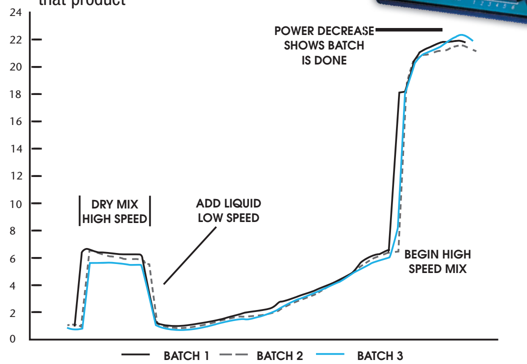
Safety Management Systems

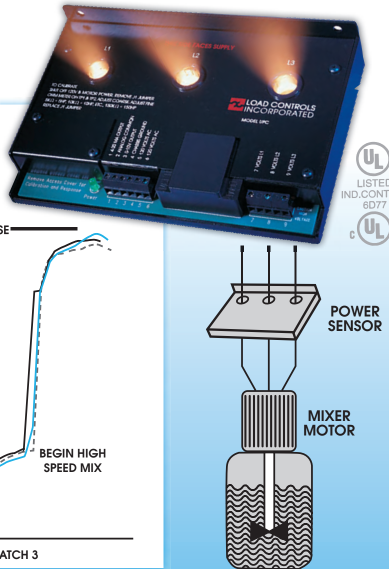
Optek-Danulat

Obtain health and safety information easily with this system
Safestations (photo) is designed to allow users access to important health and safety information quickly and easily. Using state-of-the-art touchscreen technology, plant workers can rapidly locate and access MSDS sheets on whatever substances are pertinent to their operations, as well as other health and safety information, such as Class and NFPA information, first aid, handling guidelines, emergency procedures, safety equipment requirements and and emergency response phone numbers. Booth 2139 — *Safety Management Systems, Inc., Lafayette, La.*
www.safetyms.com

An inline color sensor with two channels
The AF26 dual-channel absorption sensor (photo) precisely measures color and concentrations inline for assuring product quality, maximizing yield, minimizing product loss, detecting contaminants or preventing excessive discharge to waste-treatment facilities. Constructed for virtually all sanitary clean-in-place (CIP) or steam-in-place (SIP) procedures, the AF26 sensor can accommodate all hazardous area classifications, as well as extreme temperatures and pressures, the company says. Applications include determining chemical concentration in solutions for compounds such as Cl_2, ClO_2, hydrogen peroxide, ozone, permanganate, acids and more, as well as water disinfection, trace hydrocarbons in water and free water in refined hydrocarbons. In addition, the sensor can be used for turbidity and suspended solids measurements and more. Booth 2534 — *Optek-Danulat Inc., Germantown, Wisc.*
www.optek.com ■

Scott Jenkins





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weftec | 2012

the water quality event

Weftec 2012, the Water Environment Federation's 85th annual technical exhibition and conference, attracted over 17,000 attendees on September 29 – October 3, 2012 at the Morial Convention Center in New Orleans, La. With 980 exhibiting companies, the following is a small sampling of products and services that were on the exhibition floor.

Linde North America

Gas treatment systems for wastewater treatment

Water and wastewater treatment plants can control pH, biological oxygen demand (BOD), dissolved organics and odors with high-performance, gas-injection systems from this company. It offers oxygen, ozone and carbon dioxide gas-dissolution systems that can significantly improve treatment process efficiencies while helping to meet environmental requirements. To decrease BOD, dissolved organics and odors, the Solvox process offers an effective supplement or replacement to forced-air systems. The Solvocarb process (photo) is a fast and economical way to neutralize alkaline wastewater with a high degree of control using CO_2. When dissolved in water, CO_2 forms carbonic acid to quickly reduce pH to appropriate levels for discharge. — *Linde North America, Murray Hill, N.J.*
www.lindeus.com

A wide range of tanks and a special drain assembly

The patent-pending Full Drain Outlet (FDO) assembly (photo) for tanks of 2,500 gal and larger provides the ability to drain the tank without mechanically installed nozzles. This tank is utilized where heavy solids or salts may accumulate in the bottom of the tank. This company's full line of corrosion- and chemical-resistant tanks and containers include double wall, vertical, horizontal and conical tanks and chemical feed stations, constructed from cross-link or linear polyethylene for storing corrosive and hazardous materials. The tanks feature a wide range of capacities up to 12,000 gal. — *Assmann Corp. of America, Garrett, Ind.*
www.assmann-usa.com

Assmann

A disinfection solution that is an alternative to chlorine

Launched in May the Environmental Solutions Division (ESD) of this company integrates the company's portfolio of products to provide a new, proven wastewater-disinfection solution that offers wastewater facilities a more environmentally benign alternative to traditional chlorine technology. VigorOx WWTII is a peracetic acid formulation that controls pathogens and other microbial organisms in streams such as sewage effluent and cooling water applications. The VigorOx WWTII system is a turnkey dosing solution that includes chemical pumps, a pump controller, injection system, chemical containment system and residual analyzers. — *FMC Environmental Solutions, Philadelphia, Pa.*
www.environmental.fmc.com

Neptune Chemical Pump

An ultrasonic level transmitter for wastewater applications

The Optisound VU3X Series of continuous ultrasonic level transmitters was introduced to meet specific level or open-channel flow measurement needs for industrial and municipal applications. The Optisound VU30 ultrasonic transmitter provides reliable, repeatable and accurate (0.15%) continuous level measurement of liquids. It is capable of liquid level measurement to ranges up to 30 ft, with a 2-wire, 4–20-mA HART output signal. The Optisound VU30 sensor is constructed of chlorinated polyvinyl chloride (CPVC) for use in environments that are classified hazardous (Class I, Div. 1) with intrinsically safe or explosion-proof installation requirements, temperature ranges from –40 to 158°F and with process pressures up to 50 psig. The series features patented algorithms that allow the system to ignore most internal vessel obstructions that may be positioned directly in the ultrasonic beam path without the need for user intervention. The sensor also can be recessed in vessel nozzles to allow measurement to the very top of the vessel. — *Krohne, Peabody, Mass.*
www.us.krohne.com

Pumps designed for water applications are showcased

The Series 7000 mechanically actuated, diaphragm metering pump (photo) has been designed specifically with water and wastewater applications in mind. The mechanical design of the Series 7000 eliminates the use of contour plates on the liquid side of the diaphragm while the simple, straight-through valve and head design allows for improved flow characteristics. The Series 7000 is self-priming and has a maximum capacity range up to 300 gal/h at 150 psi. — *Neptune Chemical Pump Co., North Wales, Pa.*
www.neptune1.com ■

Dorothy Lozowski

Note: For more information, circle the 3-digit number on p. 60, or use the website designation.

CHEMICAL ENGINEERING
FACTS AT YOUR FINGERTIPS
Department Editor: Scott Jenkins

Particle-Size Reduction

For most solids-processing operations in the chemical process industries (CPI), particle-size reduction and screening (classification) to achieve the desired particle-size are required, since processes rarely produce the desired size directly. When designing processes, selecting equipment and looking for ways to increase efficiency, CPI engineers must understand the size-reduction behavior of the solid materials in their processes. To do so, they need to evaluate the following set of key properties:

- Particle-size distribution in the feed
- Particle shape
- Bulk density
- Flowability, cohesiveness and adhesiveness
- Corrosivity and composition
- Moisture content
- Hardness, brittleness and friability
- Moisture content
- Fibrous morphology
- Abrasiveness
- Stickiness
- Elasticity, plasticity and ductility
- Dust explosion characteristics
- Temperature sensitivity (degradation, stickiness and phase change)
- Toxicity
- Oil and fat content
- Reactivity or release of gases
- Shock sensitivity or explosiveness

Size-reduction mechanisms

To fracture particles, communition equipment must impart sufficient stress to the material so that it fractures as a result. Compression stress and impact stress are common, but other types exist. There are seven types of stresses that can be imparted to achieve size reduction, including the following:

- Compression between two rigid surfaces
- Compression between surfaces and adjacent bed of solids
- Shearing forces by mechanical means (tearing, cleaving, cutting or shredding)
- Shearing forces due to surrounding media
- High-velocity impact against a rigid surface
- Particle-particle impact that causes breakage and shattering
- Abrasion during particle-wall and particle-particle impacts

The energy efficiency of size reduction equipment tends to be low, and improvement of energy efficiency continues to be a key issue for both technology developers and users (Table 1).

Estimating breakage energy

The energy required for particle-size reduction is the key to designing and specifying grinding equipment. Particle-size reduction is a complex process where quantification of each contributing component is extremely difficult. It is, however, possible to make reasonable approximations using empirical relationships developed by Rittinger, Kick and Bond [*1–3*].

Rittinger postulated that the energy required for particle-size reduction is directly proportional to the amount of new surface area created.

$$E = C_R\left(\frac{1}{d_p} - \frac{1}{d_f}\right) \quad (1)$$

Where:
C_R = constant, kWh-m/ton
E = breakage energy per unit mass of feed, kWh/ton
d_f = particle size of feed, m
d_p = particle size of final product, m

Kick applied the fundamentals of plastic deformation theory and proposed that the energy required for particle-size reduction was proportional to the ratio of volume of feed particle to product particle.

$$E = C_K \ln\left(\frac{d_f}{d_p}\right) \quad (2)$$

Where:
C_K = constant, kWh/ton
E = breakage energy per unit mass of feed, kWh/ton
d_f = particle size of feed, μm
d_p = particle size of final product, μm

Bond's approach, which gives reasonable approximation for most common size-reduction processes, was based on industrial and laboratory data.

$$E = C_B\left(\sqrt{\frac{100}{d_p}} - \sqrt{\frac{100}{d_f}}\right) \quad (3)$$

Where:
C_B = Bond's work index, kWh/ton
E = breakage energy per unit mass of feed, kWh/ton
d_f = Particle size of feed defined as the sieve size though which 80% of the feed would pass through, μm
d_p = Particle size of product, as defined as the sieve size through which 80% of the product would pass, μm

Bond's work index, by definition, is the energy required per unit mass to reduce the particle size from infinity to 100 μm. It is independent of particle size, but does depend on the machine and mechanism of size reduction.

Wet grinding

In wet grinding, the surrounding medium is liquid, as opposed to dry grinding, where gas is the surrounding medium. Wet grinding should be considered in cases where the material is prone to dust explosions and static charging, or when the material is toxic and dust containment is difficult. Also wet grinding can be used when the final product size is extremely fine (production of nanoparticles is possible with wet grinding).

TABLE 1. STANDARD RANGE OF EFFICIENCIES FOR SIZE-REDUCTION EQUIPMENT [*4*]

Equipment type	Typical efficiency, %
Jaw and roll crushers	70–90
Impact crushers	30–40
Roller-ring mills	1–15
Ball mills	5–10
Impact mills	1–10

Impact mills

With impact comminution, kinetic energy of the particles to be reduced is used to generate the degree of deformation that is required for fracture. A prerequisite for impact comminution is to have a material that behaves in a brittle-elastic manner. A material is said to be brittle-elastic if the deformation of the product is initially proportional to the applied stress, and the fracture occurs suddenly. In the linear range, the particle deformation is elastic and reversible, but as soon as higher stresses are experienced, the material strength is exceeded locally, and cracks are triggered. The cracks grow extremely fast and lead to the destruction of the particle.

From experiments on single-particle impacts, the following information has been learned: that a minimum fracture energy must be applied to the particle for fracture to occur; that the probability of fracture is dependent on the kinetic energy of the particles; and that the resultant particle-size distribution is dependent on the properties of the material being processed.

There are several types of impact mills. Milling technologies are often better suited to specific applications:

- Mechanical impact mills
- Classic rotor impact mill
- Pin mill with two rotating pin discs
- Long gap mills
- Fine impact mills with air classifiers
- Jet mills

References

1. Bernotat, S. and Schonert, K. Size Reduction, in "Ullmann's Encyclopedia of Industrial Chemistry," John Wiley & Sons, 2000.
2. Rhodes, M., "Introduction to Particle Technology," 2nd ed., John Wiley & Sons, 2008.
3. Fayed, M. and Otten, L., "Handbook of Powder Science and Technology," 2nd ed., Chapman and Hall, 1997
4. Dhodapkar, S. and Theuerkauf, J. Maximizing Performance In Size Reduction, *Chem. Eng.*, June 2011, pp. 45–48.
5. Furchner, B, Fine Grinding with Impact Mills, *Chem. Eng.*, August 2009, pp. 26–33.

Editor's note: The content from this edition of "Facts at Your Fingertips" was adapted from the articles listed in refs. 4 and 5.

Dust Explosions: Prevention & Protection

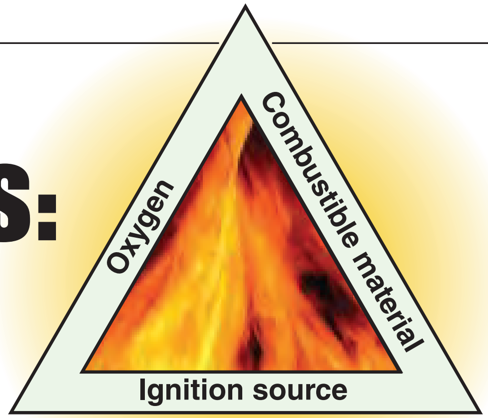

FIGURE 1. All three legs of the combustion triangle must be presnt for combustion to start

Amrit Agarwal
Pneumatic Conveying Consulting

Understand what causes these disasters and then put these practical measures in place

Preventing dust explosions is not rocket science, and still these disasters occur. This article is written to help prevent these accidents. It describes how and why these explosions happen and what can be done to avoid them.

WHY THEY OCCUR

Dust explosions occur when three conditions are present simultaneously. The first is that there is a dust cloud of a combustible material (the fuel). The second is that there is sufficient quantity of oxygen. The third is that there is an ignition source of sufficient strength. When all three conditions combine, there is combustion and then an explosion if the combustion takes place in a closed environment, such as a bin, silo, dust collector or even a building.

A large piece of wood, once ignited, will burn slowly, releasing its heat over a long time. But if this piece of wood is cut in small pieces, the combustion rate increases because the total contact surface area between the wood particles and the air has increased. If the wood pieces are cut up in very small pieces, such as 0.1 mm or less, and the particles form a dust cloud so that each particle has sufficiently large volume of air giving enough space for its unrestricted burning, the combustion rate will be very fast. If such an explosive combustion of dust takes place inside process equipment or work rooms, the pressure in the fully or partly enclosed space may rise rapidly and the process equipment or building may burst open. Figure 1 is called a combustion triangle because it has these three legs. It shows that a dust explosion can be prevented by eliminating any one of these three conditions.

Within the above three conditions, there is one more condition to consider. It is the concentration of dust particles in a dust cloud. For a dust explosion to take place, dust particles must be present in sufficient quantities in the closed gas space. The minimum quantity or concentration is called the lower explosive concentration (LEC). (This term is synonymous with the term lower explosive limit, or LEL, that is used for combustible gases). In addition to LEC, there is also an upper explosive concentration (UEC) and an optimum explosive concentration (OEC). At or above UEC, dust particles are so close to each other that they can burn but cannot cause a dust explosion. At the OEC, the severity of a dust explosion is at the maximum.

Dust explosions occur because this combustion takes place in a closed air space. During a dust explosion, dust particles burn and turn into vapor, which expands and burns other particles. The gaseous products of combustion cannot vent out from the space, thereby resulting in an increase in internal pressure. This increase in pressure results in bursting of the container in which combustion is taking place. In the closed vessel, pressure rises during an explosion because of the expanding vapor. The maximum pressure (P_{max}) that is developed depends upon a dust property called the explosivity index (K_{st}). Each dust has its own K_{st} value. The higher the K_{st}, the higher the explosivity — and the higher the pressure that is generated. Values of K_{st} and P_{max} are found by a standardized laboratory test.

A combustible dust cloud will not start to burn unless it is ignited by a source of heat of sufficient strength. The most common ignition sources are smoldering or burning materials; open flames such as from welding, cutting, matches and so on; hot surfaces such as hot bearings, dryers, heaters, compressors and so on; heat from mechanical impacts; and electrical discharges, arcs and electrostatic discharges.

A combustible dust must first be ignited before it can initiate a dust explosion. The source of ignition must have a minimum ignition energy (MIE). This is the energy that is required to initiate ignition of a dust particle. The lower the MIE, the higher the combustibility of the dust. An MIE of less than 10 mJ is considered a low MIE.

Materials that can give dust explosions are natural organic materials, such as grains, cottons, linens and sugar; synthetic organic materials, such as plastics, pigments and pesticides; coal and peat; and most metals such as aluminum, magnesium and zinc.

COLLECTING DATA ON PLANT DESIGN AND EXPLOSIVE PROPERTIES OF DUSTS BEING HANDLED

Explosive properties

It is important to know what the explosive properties of the dusts being handled are, so that the plant in which these dusts are used is designed correctly. These properties include the following considerations:

- Particle size of the dust, including its particle size distribution, if it has a range of different sizes
- Is the material fragile? Will it break up into smaller particles during the process? If so, what will be the particle size after breakage?
- Explosive properties, such as P_{max}, K_{st}, MIE, auto ignition temperature, LEC, and particle size distribution of sub-200 mesh dust
- Does the material contain combustible gases such as hydrocarbons? This will result in hybrid mixtures that are more explosive
- Can the material cause static charges?

Plant design aspects

It is important to know how the plant is being designed to make it safe against a dust explosion. Collect data such as the following:

- How is the material handled in the plant? Will there be segregation of different sized particles, resulting in concentration of very fine particles?
- Will dust accumulate in process equipment, such as dust collectors?
- Are there gravity falls of material in the plant? These falls can cause a dust cloud
- Is grinding equipment being used? Grinders create dusts and unless properly designed, can emit dust in the surrounding atmosphere
- Pneumatic conveying can break up fragile particles into dusts. Is it being used?
- If the process can emit dust inside a building, does the building have a dust collection system that prevents accumulation of dust on building surfaces? ❑

Defining explosivity

A number of parameters define the explosive characteristics of combustible solids.

Explosivity indices (P_{max} and K_{st}). The explosivity of dusts is measured in terms of two deflagration indices, namely the maximum deflagration pressure (P_{max}) and the normalized maximum rate of pressure rise (K_{st}). These indices are measured in a closed, spherical test vessel (Figure 2). P_{max} is the maximum pressure developed in a standardized test vessel during a dust explosion. K_{st} measures the severity of a dust explosion. It is related to the rate of pressure rise due to a dust explosion in a standardized test vessel. The higher the value of K_{st}, the greater the severity of the dust explosion. K_{st} is defined by Equation (1) in bars-m/s:

$$K_{st} = \frac{dp}{dt} V^{1/3} \quad (1)$$

Where:

p = Pressure in the test vessel, bar

t = Time, s

V = Volume of the test vessel, m^3

$\frac{dp}{dt}$ = Rate of pressure rise in the test vessel

Heat of combustion. The heat of combustion of the material is an important parameter because it determines the amount of heat that is liberated in the explosion. Heat is liberated due to oxidation of the material. Metals such as aluminum and magnesium have much higher heat generation than organic dusts and coal. The result is that the temperatures of flames of metallic dusts such as aluminum and magnesium are very high compared with those of flames of organic dusts.

Particle size and particle size distribution (PSD). Explosiveness of a dust depends upon the particle size. In general, particles larger than about 400 microns or about 35 mesh, can burn, but not explode. Particles larger than 120 mesh can burn and explode, but the severity of the dust explosion is not very high. Particles smaller than 200 mesh are most explosive and are used to determine the dust's explosive properties such as its K_{st}, MIE and LEC values.

As the particle size of a sub-200 mesh dust decreases, dust becomes more and more explosive for the following reasons:

- Its MIE decreases
- Its P_{max} and K_{st} increase

Hybrid mixtures are mixtures of combustible gases, oxygen and combustible dusts. Hybrid mixtures are much more explosive than mixtures of combustible dusts and oxygen.

Dust classes. NFPA (National Fire Protection Association) classifications for various dusts are Class 1, Class 2 and Class 3. Class 1 is the least explosive dust, and Class 3 is the most explosive dust. Examples of these three classes of dusts are as follows:

- Class 1 dusts (K_{st} = 1–200 bar-m/s): Coal, flour, starch, sugar, grain, powdered milk, polyethylene, polypropylene, epoxy resin and sulfur
- Class 2 dusts (K_{st} = 201–300 bar-m/s): Organic pigment, wood, cellulose and cork
- Class 3 dusts (K_{st} > 300 bar-m/s): Aluminum, magnesium and calcium

EXPLOSION PROTECTION AND PREVENTION

If the data on the material being handled show that its dust is explosive, steps must be taken to prevent a dust explosion. These steps are given below.

Precautionary methods

Implement proper housekeeping procedures to minimize formation of a dust cloud anywhere in the building or inside process equipment. Meanwhile, minimize the probability of having a source of ignition by adopting safe housekeeping procedures and proper electrical classification. These two methods are described in more detail below.

1. Control dust emissions and accumulation. Good housekeeping should be maintained at all times in buildings and other confined spaces to keep them free from dust concentrations. Good housekeeping is essential to prevent accumulation of dusts inside buildings or in structures, because these accumulations can result in secondary dust explosions.

Dust should not be allowed to accumulate in layers on equipment, building walls, floors or structural members. Install building venting and dust collection if good housekeeping cannot be maintained. The preferred method for dust removal is by means of properly designed vacuum-cleaning equipment. Dispersion of the dust, which results in formation of a dust cloud, must be prevented.

Meanwhile, keep the following best practices in mind:

- *Dust tight process:* All process components must be dust tight
- *Dust collection:* For process components that cannot be made dust tight, vent hoods and dust collectors must be installed to remove and collect emitted dust
- *Pneumatic-conveying system design*: All equipment and piping must be of dust-tight design to avoid emission of dust. Piping must be designed to withstand the maximum explosion pressure without exceeding two-thirds of the burst pressure. In case of a filter element failure, blower outlets and dust-collector outlets are located outside closed buildings to prevent formation of a dust cloud inside a building or a structure.

2. Control ignition sources. Equipment design and arrangement, good maintenance and good housekeeping are all necessary to minimize the potential for ignition of dusts by electrical equipment or other equipment that might have high surface temperatures.

In the U.S., all electrical installations and equipment designs should meet the requirements prescribed in the U.S. National Electrical Code. This code classifies processing or manufacturing areas involving combustible materials according to class, group and division.

- *Class* refers to broad categories of combustible materials, where Class I includes all combustible vapors and gases, and Class II includes all combustible dusts
- *Group* further defines the classes based on the ease of ignition or the rate of combustion of the combustible material
- *Division* specifies the time periods, frequency and length, during which the combustible material is present
- *Unclassified areas* are areas that contain no significant amount of combustible material at any time. Electrical equipment installed in unclassified areas should meet certain minimum standards to maintain operability and prevent personnel hazards

Once it has been determined that a particular area may contain combustible materials, it is necessary to classify the area according to Division and Group.

- *Division 1* locations are defined as those where flammable or combustible mixtures are normally present in sufficient quantities to present a hazard
- *Division 2* locations are those where flammable or combustible mixtures are not normally present, but might be present as the result of infrequent malfunctioning of equipment

Based on the physical characteristics of the materials handled, flammable vapors or gases are assigned to Groups A, B, C or D, and combustible dusts are assigned to Groups E or G.

Bonding and grounding: Energy levels far greater than 15 mJ, easily sufficient to ignite some dusts, are obtainable via spark discharges from ungrounded conductors. To dissipate static electricity, adequate bonding and grounding must be provided for solids handling equipment and components, including conveying, feeding, blending and storage systems. Bonding is the process of electrically connecting conductive components together so that these are at the same electrical potential, and no sparks can occur between them. Equipment such as a baghouse can be comprised of a number of individual components: bag cages, bag clamps, bag grounding wire and so on. In such cases, it is important that each of the components is properly grounded and integrity of the grounding system is routinely checked. Resistance to ground shall be measured and documented for each major component.

Equipment skin-temperature limi-

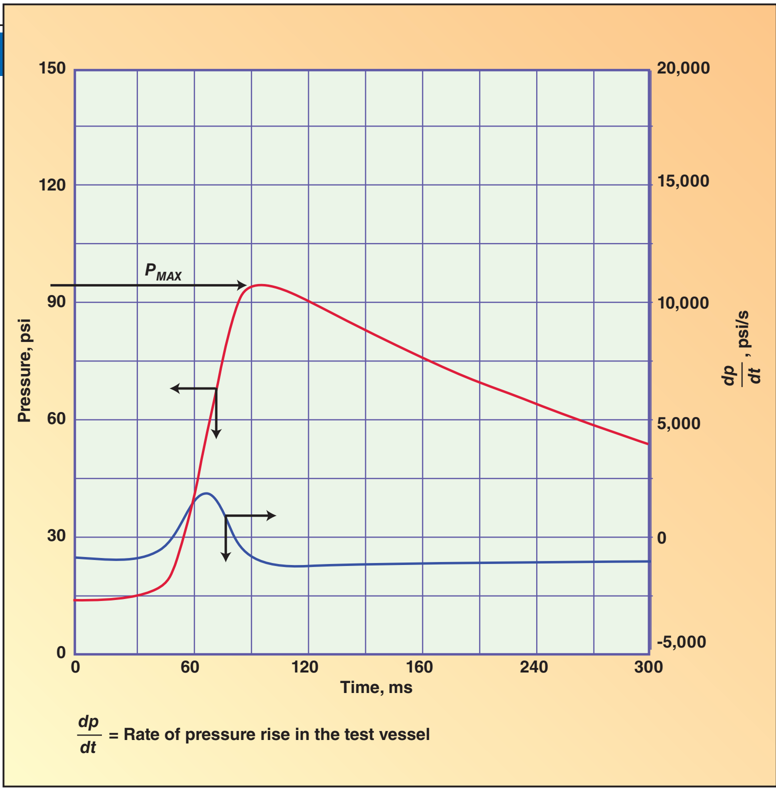

FIGURE 2. In typical tests results, P_{max} is the top peak of the red line, while the maximum rate of pressure rise (*dp/dt*) is used with Equation (1) to determine K_{st}

tations: In addition to establishing a number of other design and installation requirements, the skin (outside surface) temperature of any equipment should not exceed 80% of the auto ignition temperature (AIT) for the dust being used.

Maintenance: Maintenance must be provided to assure the integrity of dust-tight electrical equipment. Periodic inspection is required to detect and remove buildup of combustible dusts inside the electrical equipment.

Design methods

When handling explosive dusts, the following standards are used to design the dust-explosion prevention or protection systems:

- NFPA 68: Explosion venting
- NFPA 69: Explosion prevention
- NFPA 497M: Electrical classification of gases, vapors and dusts for electrical equipment in hazardous (classified) locations
- NFPA 650: Pneumatic conveying systems for handling of combustible materials
- NFPA 654: Fire and explosion prevention in chemical, dye, pharmaceutical and plastics industries

The use of these standards is described below in more detail.

Explosion suppression systems. Explosion suppression systems prevent high explosive pressures from developing in vessels by suppressing an explosion from starting at its source. These systems consist of a detector system that senses the start of an explosion, a pressurized container with an extinguishing medium, and a fast-opening valve that is activated by a pressure sensor through a control-monitoring unit. The extinguishing medium is dispersed into the protected vessel in a very short time in order to reduce the expected maximum pressure to a substantially lower level. The detectors that trigger the explosion-suppression system are able to start the suppression system rapidly. There are three different types of sensors: thermoelectric, optical and pressure. Pressure sensors are used more widely. The containers of the extinguishing medium are equipped with fast-acting valves, which open fully within milliseconds after the activation signal is given. The valves are designed to uniformly distribute the whole contents of the extinguishing medium within a very short time.

To prevent flashback from occurring, a positive method of isolating the explosion is required. For this isolation, devices such as mechanical decouplers, or fast-acting shut-off valves are used to isolate the vessel.

The explosion-suppression method is cost prohibitive for large equipment and vessels, such as bins and silos. It also requires diligent upkeep of the control systems so that timely operation of the valves is not affected.

Explosion pressure containment. Explosion pressure containment is a technique to protect small-sized equipment by designing it to withstand the internal pressure that is generated by an explosion. This technique is cost prohibitive for large vessels such as bins and silos.

Vessels designed for explosion pressure containment are to be designed and constructed according to the ASME Pressure Vessel Code.

The design pressure of the vessel is based on either the ultimate strength of the vessel or on the yield strength of the vessel.

The vessel is designed so that the peak explosion pressure is less than two thirds of the vessel burst pressure. Vessel design pressure is calculated by using the method given in NFPA 69:

$$P_r = \frac{1.5P_{max}}{F_u} \qquad \textbf{(2)}$$

Where:

F_u = Ratio of ultimate stress divided by the stress generated at the design pressure

P_r = Vessel design pressure to prevent vessel rupture, psig

P_{max} = Maximum deflagration pressure, psig

Note: If it is desired that the vessel not be damaged as a result of the explosion, then F_y (the ratio of the yield stress divided by the stress at the design pressure) should be substituted for the ultimate stress in the above equation. Yield stress is the stress at which that the material deforms permanently; ultimate tensile stress is the stress at which it breaks.

Inerting. This design method is used to prevent dust explosions by reducing the oxygen concentration to less than that needed to support an explosion. It is the preferred design method for ignition-sensitive dusts. Ignition sensitive dusts are those whose sub-200-mesh fraction has an MIE less than 10 mJ. It is also used for hybrid dusts (dusts containing combustible gases).

When sufficient inert gas (typically nitrogen) is introduced, the volumetric concentration of oxygen is reduced to such a level that no ignition of the dust, combustible-gas and air mixture can occur. The inert gas must not be contaminated by air or hydrocarbons.

A minimum safety factor of 2-vol.% should be provided below the limiting oxygen concentration (LOC) if either of the following are true:

- Oxygen-limiting control equipment, analyzers and interlocks are installed to take positive action to prevent formation of an explosive mixture in the event of a failure (with a pre-alarm and a shutdown alarm)
- Or, if interlocks are not installed, alarms should be provided, and operating procedures should be in place to prevent formation of a mixture exceeding the maximum oxygen concentration above which deflagration can take place

If oxygen analyzers and alarms are not used, the maximum oxygen concentration shall be maintained at no more than 60% of the LOC, alarms must be provided on loss of the inert gas flow or pressure, and the oxygen concentration must be checked on a regularly scheduled basis. The integrity and consistency of all inerting facilities must be established by periodic checking of the oxygen concentration. Low-flow alarms should be used if procedures cannot be relied upon to ensure that the inert gas is turned on.

For those operations relying entirely on control of oxidant as the means of explosion protection (for instance, no explosion venting or other methods for explosion protection are provided), the percent O_2 and inert-gas flow systems should be considered as critical controls.

Maximum oxygen concentrations for typical dusts can be found in NFPA 69.

Dust explosion venting method. This method is used to prevent catastrophic damage to equipment and facilities by properly venting a dust explosion to the outside atmosphere. It assumes that oxygen, a combustible mixture and a sufficiently strong ignition source are present so that a dust explosion can occur. Catastrophic vessel failure is prevented by providing rupture panels on vessels for pressure relief and for discharge of the explosive material, and by designing rupture panels so that the peak explosion pressure is less than two thirds of the vessel burst pressure.

The rupture panels are also called vents. Vents are openings in a vessel through which combustion-generated gases can expand and flow out. These vents serve to limit the deflagration pressure so that damage to the enclosure is limited to an acceptable level or is eliminated entirely. The area of the vents must be large enough to limit the explosion pressure to a safe level. Vents are designed so that they rupture and blow out, thus reducing the pressure inside the vessel to a level that is below the rupture-pressure rating of the vessel.

The rate of pressure rise is an important parameter in the venting of an explosion. It determines the time that is available for the products of combustion to escape from the enclosure and for the pressure to dissipate. The higher this rate, the greater the venting area that is required.

The vessel or equipment must be designed to withstand the maximum pressure attained during the venting process without catastrophic failure. Some yielding of the vessel or equipment is acceptable during a vented deflagration. For example, partial failure of the roof-to-shell seam of a vessel is not considered catastrophic failure.

Maximum pressure during venting (P_{red}) should not exceed two thirds of the static burst pressure of the protected equipment. If P_{red} exceeds 10 psig, an ASME Code vessel is required.

The vent opening pressure (P_{stat}) should be set as low as practical to minimize the rise in internal vessel pressure before the explosion is vented. This reduces the potential for damage, and for a given vent size, will result in a lower maximum pressure during venting. However, P_{stat} must be high enough to prevent premature opening of the vent by the combination of normal vessel-operating pressures and wind loads.

The following method for calculating required venting area (A_v, m^2) is given in NFPA 68 and here in Equation (3):

$$A_v = a\left(V^{2/3}\right)\left(K_{st}\right)^b\left(P_{red}\right)^c \quad (3)$$

Where:
A_v = Required venting area, m^2
$a = 5.71 \times 10^{-4} \exp(2\,P_{stat})$
$b = 0.978 \exp(-0.105\,P_{stat})$
$c = -0.687 \exp(0.0226\,P_{stat})$
V = Empty vessel volume, m^3
K_{st} = Dust deflagration index, bar-m/s
P_{red} = The reduced pressure (the maximum pressure actually developed in the vessel during a vented explosion), barg. The maximum pressure developed during a vented deflagration (P_{red}) should not exceed 2/3 burst of the vessel burst pressure.
P_{stat} = Pressure at which the relief device opens, barg. This is the pressure at which the vent is expected to open. It should be at least 0.5 psi greater than the peak operating pressure of the equipment. The minimum P_{stat} used in the venting equations is 0.1 barg (1.45 psig).

The following best practices should be observed for vents:

- Vents should be designed to give a free, unobstructed opening during a deflagration
- Access of personnel to areas that could be exposed to fireballs coming out from the deflagration vents should be restricted unless deflector shields are provided. Shields should not interfere with the venting process
- Panels shall be adequately tethered by using chains or cables, where practical, to prevent them from becoming missiles during the venting process
- Vent panels should be located so that they are not obstructed by the solids' level in the vessel. For example, by ensuring that the vent panel bottoms are at least 1 ft higher than the maximum solids level
- Where side vent panels are used, they should be symmetrically arranged around the perimeter of the vented vessel
- All equipment using explosion relief panels should be located outside of closed structures or buildings. If this is not possible and the equipment volume exceeds 8 ft^3, the equipment is to be vented to the outside through a properly designed duct
- Vent panels should be manufactured by vendors who have special expertise in their design and testing
- Vents can fail by rupture (for instance, metal fails in tension), or they can fail by blowing out from their frames or by failure of their fasteners. When fasteners are used, avoid spring-loaded latching devices because they are not reliable

Buildings. Buildings that have properly designed and maintained dust handling and process equipment do not require explosion venting. However, damage-limiting construction of the building is desirable. In locations where environmental dust-concentration conditions exist, such as due to poor maintenance and housekeeping, building explosion venting should be provided, as given in NFPA 68.

Dust collectors and bag houses. Dust collectors and bag houses pose significant dust explosion hazards because they inherently have a dusty internal environment. Their tube sheets and bag cages must be properly bonded and grounded to prevent ignition caused by static charges. Properly designed explosion vents should be provided on the dusty side of the dust collector. Dust collectors should be located outside of buildings or located close to external walls. When installed above bins and silos as bin vent filters, use a rotary valve to prevent propagation of a dust explosion into the bin or silo. When handling low-MIE dusts use the inerting method, as described previously, instead of explosion vents. ■

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Toshiba International

FIGURE 1. A fan is the only moving part of a variable frequency drive

Feature Report

Variable Frequency Drives for Centrifugal Pumps

Joseph T. Ramey
Westchase Design, L.L.C.

A method to estimate the economics of using variable frequency drives

The prices of low-voltage variable frequency drives (VFDs) have declined substantially since they were introduced, while the cost of power has increased. Normal project economics will now justify these VFDs — which go up to 375 kW (500 hp) or beyond — for pumps over the largest part of the range of application of the pumps. To efficiently evaluate and apply VFDs, process engineers need to know certain elementary things about them. They also need to know about the interactions of pumps and hydraulics when the pumps run at variable speeds. Further economic evaluation beyond the approximate method must be performed, but because low-voltage VFDs require only a small incremental capital investment, their application cannot justify a very detailed evaluation. Usually, screening level economics — as presented here — must be applied and some uncertainty must be accepted.

Introduction

A VFD (Figure 1) comprises a rectifier, which converts an alternating current into a direct current, followed by an inverter, which converts that direct current into a coarse version of an alternating current. These operations are depicted in a simplified manner in Figure 2, which represents a single-phase current or one phase of a three-phase current. The frequency of the alternating current that is produced is set by the inverter, and when that current is fed to an electric motor, its frequency controls the speed of the motor. For this reason, VFDs are sometimes called variable speed drives (VSDs) or adjustable speed drives (ASDs), but the more common and fundamental term VFD is used in this article. Varying the speed of a centrifugal pump controls the head and capacity of the pump.

If a VFD is not used, the conventional method of controlling a centrifugal pump circuit is with a control valve that throttles the discharge of the pump. The control valve consumes the excess head that the pump produces at the desired flowrate, thereby setting the desired flowrate. An alternative method, which places the control valve in a bypass from the discharge of the pump to its suction, is typically used for positive displacement pumps but is also used for centrifugal pumps sometimes. This method is only mentioned here but would have to be considered in the evaluation of a specific case if it is the conventional method that would be used. These schemes are shown in a simplified manner in Figures 3A and 3B, and the scheme for using a VFD is shown in Figure 3C. When a VFD is used, the control valve is deleted, and the speed of the pump is adjusted to provide the exact head that is required, thereby saving the energy that would have been dissipated across the control valve.

Except for what is necessary to discuss VFDs, this article does not cover the fundamentals of pumps and hydraulics. Readers wishing to review the fundamentals may consult Ref. 1–3 for pumps, Ref. 4 and 5 for hydraulics, or other standard references. Having a control valve in the discharge of the pump is used as the base case for the comparison with a VFD case in this article. Moreover, only services on a single operating curve with continuous operation are considered. Shukla and others [*6*] describe the method to calculate the power savings when there are two or more services on different operating curves, and may be consulted if necessary. The choices made for this article, however, cover most of the pumping services that are likely to be encountered.

Although they saved energy, VFDs were so expensive when they were introduced that their energy savings could not offset their costs in a time period that would have been acceptable in normal project evaluations. Prices have declined, especially for low-voltage (480 V) VFDs, and energy prices have increased. The perception of VFDs being uneconomical has persisted in the minds of many, however, and that perception combined with the push to shorten design schedules has frequently caused VFDs to not be considered on a routine basis. They should be. Low-voltage VFDs can now be justified by normal project economics throughout most of the range of their application to centrifugal pumps.

VFD considerations

To evaluate VFD applications for centrifugal pumps, process engineers need to know a number of things about them, but this knowledge does not need to be extensive. This is fortunate because some of the information received on the electrical aspects is seemingly inconsistent and is assumed to be explained by the different recommendations and design practices of the various manufacturers, owners and engineering firms. A firm's electrical engineers will handle the electrical design, including the VFD selection, in accordance with the applicable design practices. Process engineers need only perform preliminary economic evaluations accordingly and be aware of the issues. The knowledge of the issues will allow them to understand any interaction with the process design, to communicate effectively with the rest of the project team, and to prevent the unnecessary repetition of work. It will also help in applying judgment to the results of evaluation methods.

Maintenance. VFDs are solid state devices that require very little maintenance. Above a certain size, they require a fan for cooling, which is the only moving part. In addition to requiring periodic cleaning, the fan is the most likely component to fail. An approximate mean-time-between-failures for VFDs has been given as 10 years.

Motors. Not all electric motors are capable of operating on an inverter, but the severe-duty motors that are typically specified for CPI centrifugal pumps are likely to be adequate. The potential problem is that a fan that is directly connected to the shaft of the motor slows down when the speed of the motor slows down and therefore may not provide adequate cooling in that situation. A large turndown may require an auxiliary fan motor to keep the fan turning adequately while the speed of the main motor is reduced. Centrifugal pumps generally require an approximate 4:1 turndown to cover their continuous operating range, and require a greater turndown only briefly at startup. A severe-duty motor will normally meet this requirement.

Some pumps, such as positive displacement pumps, can require a greater turndown to cover their continuous operating range. Many firms now specify that motors for centrifugal pumps be capable of operating on inverters whether or not they are contemplating using VFDs at the time. Inverter-capable motors are an important, but minor, consideration for new installations, although they could be a major cost in retrofits. The existing motors should be checked early in these projects.

Cable types. Motors operating on inverters require cables with better insulation and shielding than if they were operating directly on a.c. circuits [*7, 8*]. An approximate cost for this upgrade of the cables to go with a mid-sized low-voltage VFD is \$3/m (\$1/ft). Some sources have said that they would use heavier cables with VFDs, but a published reference was not readily found. The cost of the cables is a minor issue for new installations, but the suitability of existing cables could be a significant issue for retrofits and should be checked early. For new applications, some firms design the cables to be capable of handling inverters whether or not VFDs are being considered at the time.

Cable length. With a VFD, the length of the cable to the motor must be limited. For certain types of motors, base maximum lengths as low as 50 m (150 ft) have been mentioned. Some installation manuals [*9–11*] give more typical maximum lengths as 100–300 m (300–1,000 ft) depending on several parameters including switching frequency, electromagnetic compatibility (EMC) limits, and size. These lengths may be extended with external filters at additional cost, but there are still limits that cannot be exceeded.

Starter. A VFD has the capability to be a starter for the motor and does not require that the motor have a separate starter. The VFD has a mode that starts the motor at the minimum speed and increases it at a predetermined rate until the set speed is reached. This is called a soft-start and is a desirable characteristic that reduces the impact on the pump and the motor. Thus, the VFD not only has starting capability, it has the best type of starting capability and there is no reason to have a separate starter. In an evaluation of the economics, a case with a VFD has a credit for not having to pay for a starter.

Location. In the CPI, VFDs are usually located in buildings, which reduces the costs for the VFDs because the VFDs can have minimal enclosures. Some designs have the VFDs and other electrical controls for the motor in a single enclosure with slots for the various components. In other designs the VFDs are separate or even in separate buildings. The choice of the design may depend on the owner's or the engineering firm's standards. It may also be influenced by maximum cable lengths.

Installation. There is no installation cost, or a low installation cost, for a VFD. This is easy to see if all of the motor controls (including the starter or the VFD) are in a single enclosure. The connections to the enclosure would be the same whether it contained a starter or a VFD. If the VFD is separate, additional connections would be required, but this is a minor cost. The cost for the connection of a control signal to a VFD would be the same as that to a control valve. If the cost estimator uses a Guthrie-type factor on the equipment cost of the pump and motor to calculate the installation cost, the cost of the VFD must be excluded from the equipment cost or the factor must be adjusted to compensate. If some of the items mentioned previously, such as more expensive cables, will not be the same for cases with and without VFDs, the cost differences may need to be considered.

Loss. Instead of stating an efficiency for a VFD, the manufacturers state a loss. For each size, the manufacturer gives a constant loss, which is split into an internal loss in the VFD and an induced loss in the rest of the circuit. Although they vary, the total losses are about 1.8% of the nominal power of the drives.

Motor efficiency. Reducing the speed

NOMENCLATURE

a.c.	Alternating current
API	American Petroleum Institute
C_1–C_6	Constants
d	Inside pipe diameter
EMC	Electromagnetic compatibility
f	Friction factor
H	Head
HAZOP	Hazards and operability analysis
L	Equivalent length
n	Rotational speed
PFD	Process flow diagram
Q	Pump capacity, volume rate of flow
VFD	Variable frequency drive
VSD	Variable speed drive
W	Power
ΔP	Differential pressure
ε_M	Motor efficiency
ε_P	Pump efficiency
ε_V	VFD efficiency
ρ	Density

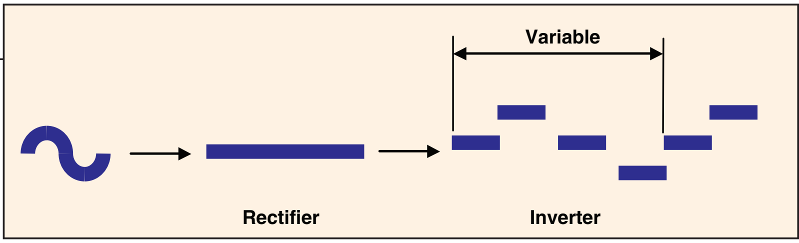

FIGURE 2. A simplified diagram of how a variable frequency drive works

of an electric motor with a VFD does not, on average, reduce the efficiency of the motor. A report by Burt and others [*12*] of the Irrigation Training and Research Center at the California Polytechnic State University indicated that although there was variation among the motors tested, the average of the efficiency was almost precisely a function of load only.

Torque. VFDs can be supplied to handle fixed-torque applications or variable-torque applications. A fixed-torque application, such as a hoist or a conveyor, requires a more expensive VFD, but a pump is a variable-torque application. Consequently, it can use a less expensive VFD.

Harmonics. VFDs can create harmonics in electrical circuits, and more expensive VFDs are required to mitigate harmonics if the VFDs are to operate on sensitive circuits. CPI pump circuits are not sensitive and can use less expensive VFDs.

Turndown. The turndown on a VFD is about 120:1, which is more than adequate for centrifugal pumps.

Failure mode. The failure mode of a VFD is to turn off. This generates a pressure-relief contingency similar to that from the trip of the circuit breaker on a pump's motor circuit.

Operating error. An operating error on a VFD can lead to a pump being run at maximum speed. This generates a pressure-relief contingency similar to that from an inadvertent control valve opening with a fixed-speed pump. The contingency may or may not be more severe.

Pumps at variable speeds

Process engineers also need to know, or review, some concepts about centrifugal pumps that are operating at variable speeds. The concept of a minimum stable flow for a centrifugal pump operating at a fixed speed is a familiar one. A rule-of-thumb for pumps with a discharge diameter of 25 mm (1 in.) or larger states that the minimum stable flow is approximately 30% of the flow at the best efficiency point. The concept that pumps also have a minimum permissible speed and a maximum permissible speed may be less familiar. A rule-of-thumb for a typical centrifugal pump states that the minimum permissible speed (and flow) is approximately 25% of that at the rated point. The rated point is usually placed at a lower flow than that at the best efficiency point. Consequently, the rules-of-thumb suggest that a typical pump operating at a variable speed can obtain a lower minimum stable flow than one operating at a fixed speed. The difference might allow a pump operating at a variable speed to do without a minimum flow bypass in a region where a pump operating at a fixed speed could not. The above approximations are valuable for preliminary thinking, but the manufacturer's values for the minimum stable flow, minimum permissible speed, and maximum permissible speed must be used for design.

A centrifugal pump with a VFD consumes less power than a centrifugal pump with a control valve, but the amount of power saved differs markedly with the type of hydraulic system that produces the head requirement for the pump. First, consider a system with all static head. The pump affinity laws give the variation of the head and capacity with speed of a centrifugal pump at a constant impeller diameter as follows:

$$\frac{Q_2}{Q_1} = \frac{n_2}{n_1} \qquad (1)$$

$$\frac{H_2}{H_1} = \frac{n_2^2}{n_1^2} \qquad (2)$$

Where Q is the volumetric flowrate (usually in m³/h or gal/min), n is the rotational speed (usually in revolutions per minute, rpm), and H is head (usually in m or ft). Combining Equations (1) and (2) gives:

$$\frac{H_2}{H_1} = \frac{Q_2^2}{Q_1^2} \qquad (3)$$

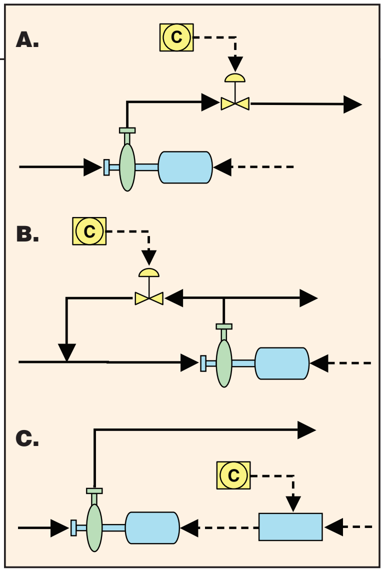

FIGURE 3. Shown here are three typical control schemes for A) a centrifugal pump using a control valve; B) A positive displacement pump using a control valve; and C) A pump using a variable frequency drive

Looking at either Equations (1) and (2) or at Equation (3) shows that the head changes faster than the flowrate when the speed is changed. Figure 4 illustrates pump curves for the case where all of the system pressure drop is static pressure drop. A system curve is the plot of the required head versus the flowrate for the pump's hydraulic circuit excluding any control valve. In this case, it is the horizontal line shown in red. The violet line shows the pump curve for a fixed-speed pump that uses a control valve. Point 1 represents the rated point for the pump, and the double-headed arrow shows the excess head that must be consumed by the control valve. The green line shows the pump curve for a pump with a VFD whose speed has been adjusted, in accordance with Equation (3), to provide exactly the head required at the rated point. Point 2 represents an operation turned down to a lower flowrate. Again, the double-headed arrow shows the excess head that must be consumed by the control valve for the fixed-speed pump. The blue line shows the pump curve for the pump with a VFD whose speed has been adjusted to provide exactly the head required at the point. There is not much difference between the operation of the pumps with and without a VFD. The operating point backs up on the pump curve in both cases.

Figure 5 illustrates an efficiency curve for a typical centrifugal pump,

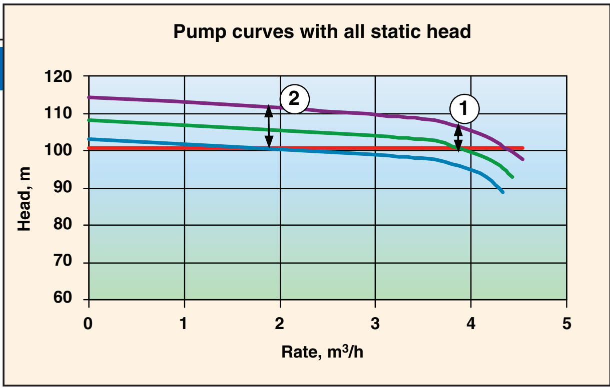

FIGURE 4. Pump curves for the case of all static pressure drop show the limited opportunity for energy savings (violet is fixed speed pump, green and blue are with a VFD and red is the system curve)

but not the same pump whose curves are shown in Figure 4. Pumps are usually selected such that the rated point falls at a lower flowrate than the best efficiency point of the pump. Accordingly, when the operating point backs up on the pump curve, the efficiency decreases. The operating point for the pump with the VFD is a little closer to the best efficiency point than that of the pump operating at fixed speed, so the pump with the VFD is predicted to have a slightly higher efficiency. The formula for the hydraulic power of a pump is given [*13*] as follows with the numerical constant replaced by C_1 to make the equation independent of a specific set of units:

$$W = \frac{(\Delta P)Q}{C_1} \quad (4)$$

Where W is power (typically kW or hp) and ΔP is pressure drop (typically kPa, kg/cm^2 or psi). Equation (4) is restated with efficiencies introduced to give electrical power.

$$W = \frac{(\Delta P)Q}{C_1 \varepsilon_P \varepsilon_M \varepsilon_V} \quad (5)$$

Where ε_P is pump efficiency, ε_M is motor efficiency and ε_V is VFD efficiency. The VFD loss has been restated as an efficiency for consistency with the other terms. Equation (5) shows why the advantage for the VFD is small. The difference in pressure drop between the two cases is small. Note that the zero in Figure 4 has been suppressed to show the differences clearly. The pump with the VFD has a slightly higher efficiency. However, the constant loss of the VFD translates into a decreasing efficiency when the power is reduced. This works against the two advantages of the VFD case. In any event, the differences are small.

Now, consider the case of all-frictional pressure drop and small differences are most emphatically not the case. The Darcy equation for frictional pressure drop in pipe [*14*] is used to calculate the system curve and is stated as follows:

$$\Delta P = \frac{C_2 f L \rho Q^2}{d^5} \quad (6)$$

Where ΔP is pressure drop (usually kPa, kg/cm^2, or psi); C_2 replaces the numerical constant to make the equation independent of a set of units. The subscript merely emphasizes that the constant is numerically different from other constants; f is the friction factor; L is the length or the equivalent length, (usually m or ft); ρ is density (usually kg/m^3 or lb/ft^3); and the internal diameter is d (usually mm or in.). The formula for converting pressure drop to head loss, which will be used in pump calculations, is:

$$\Delta P = \frac{H\rho}{C_3} \quad (7)$$

Where H is the head loss (usually m or ft). Combining to state the pressure drop as head loss gives:

$$H = \frac{C_4 f L Q^2}{d^5} \quad (8)$$

The friction factor is constant for well-developed turbulent flow, which is the usual situation for pump circuits. The length is used as the equivalent length of all pipe, fittings and equipment. It is constant for a given circuit and so is the diameter of the pipe. Equation (8) reduces to:

$$H = C_5 Q^2 \quad (9)$$

Which is a familiar relationship. When the flow is reduced, the head loss, or ΔP, is reduced by the square of the flow. This provides an excellent opportunity for saving power as shown by Equation (5). Also, if Equation (9) is applied at two points and the equations divided, the result is:

$$\frac{H_2}{H_1} = \frac{Q_2^2}{Q_1^2} \quad (10)$$

Where the subscripts indicate the points. Equations (9) and (10) apply to the system curve. Equation (10) is identical to Equation (3), the affinity law; consequently the same equation also connects corresponding points on the pump curves for different speeds.

The pump curves and system curve, shown in Figure 6, illustrate the greater potential for energy savings when the head loss is all frictional. As with the curves for the situation with all static loss, the violet pump curve represents the case with a fixed pump speed and a control valve. The green pump curve represents the case with a VFD reducing the speed of the pump. The red curve represents both the system curve and the curve that connects corresponding points on the pump curves. Point 1 is an operation at a reduced flowrate, where the double-headed arrow indicates the head loss being consumed by the control valve as in the case with the control valve. The operating point has backed up on the pump curve, like the case with the all-static pressure drop, and the pump efficiency has declined similarly. In the case with the VFD, the operating point at the lower speed corresponds to the rated point, therefore the pump efficiency is about the same.

An examination of the efficiencies of a few API 610 pumps at standard fixed-speeds showed that the efficiency declined by less than 2% for a 50% reduction in speed and less than 3% for a 75% reduction. Given the few points considered and the considerable scatter, a linear relation through the points stated is as good of a representation as is justified in this range, but it seems obvious that the relationship could not be approximately linear over a longer range. The percent reduction stated is a percentage of the percent efficiency. The reduction in efficiency agrees roughly with Shukla and others [*6*] who cite a 3–4% reduction for

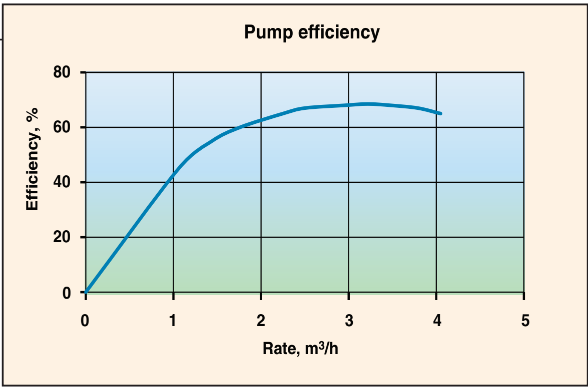

FIGURE 5. An efficiency curve for a typical centrifugal pump

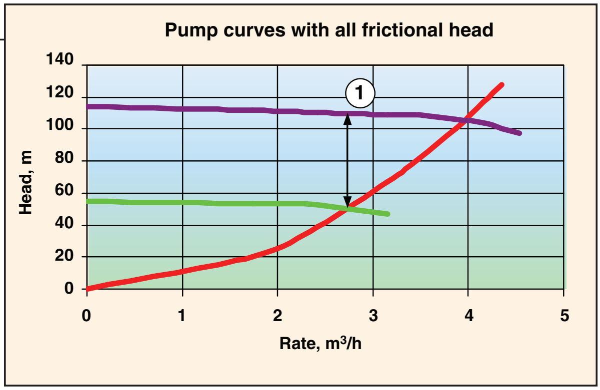

FIGURE 6. These pump curves show the greater potential for energy savings when the head loss is all frictional compared with static (compare Figure 4)

the entire pump range from rated flow to minimum flow.

These considerations show that the efficiency declines a little when the speed is reduced, but it does not decline to the extent that it does in the case of reduced flow at constant speed. In addition, the red curve representing the system curve shows that the required pump head decreases rapidly with decreasing flow. This is also shown by Equation (9), which indicates that the head decreases as the square of the flow. The power required in the case with the VFD is less for three reasons: (1) the pump does not back up on its curve, (2) the pump nearly maintains its efficiency when the speed is reduced, and (3) the pump requires less head when the flow decreases.

Equation (9) shows that the head (or pressure drop) is a function of the square of the flowrate. If the head is stated as pressure drop (ΔP) and substituted into Equation (5), the result is Equation (11):

$$W = \frac{Q^3}{C_6 \varepsilon_P \varepsilon_M \varepsilon_V} \qquad (11)$$

Which shows that the power is proportional to the cube of the flow for frictional pressure drop. This equation and Figure 6 illustrate the concept that different flowrates cannot be averaged linearly to calculate the power at an average flowrate.

This section has shown that two parameters, the percentage of the total pressure drop that is frictional (as opposed to static) and the turndown in the flow, are important in evaluating the case for using a VFD with a centrifugal pump. Like any economic evaluation, the basis for the evaluation must be established first.

Basis information

The owner usually sets the bases for an economic evaluation because many of the bases represent business decisions rather than engineering decisions. However, an engineering firm may make recommendations if requested to do so. In a formal project, the owner provides the basis documents such as the basic engineering design data and the process design basis. The owner's engineering standards, safety standards and operating procedures will also usually apply. Engineering firms should be ready to solicit whatever information or alternative directions that the owner wants to supply if they are not already offered. If the evaluation is being done within the owner's organization, it is still a good idea to have the bases set, perhaps more informally, before starting the evaluation. Some of the items to be considered are as follows:

Power cost. If there are different power sources, the cost will be the marginal cost for increasing or reducing power. Any escalation or de-escalation to be applied also needs to be supplied.

Payout time. Simple payout time is used for the criterion in this article and as an example. The general payout time that is specified for the project may be used, or a longer payout time may be allowed for power savings. Some owners consider that utility savings are more certain than the general project economics based on marketing projections, and therefore are deserving of a less stringent payout criterion.

Turndown pattern. If, for example, a project is expected to operate at a lower capacity in the initial period of its operation, this information needs to be supplied.

Voltages. If the owner is specifying what voltages are to be used for what motor sizes, this information needs to be supplied.

Approved vendors. If purchases must be limited to approved vendors, the list must be supplied.

Existing equipment. Information on existing equipment that is to be considered for the project needs to be supplied as well as the cost to be charged for the equipment, if any.

Owner's costs. Engineering firms typically exclude from cost estimates a category of costs termed owner's costs. For a design alternate study of a VFD in a new pump service, these costs offset. For a retrofit, however, they do not and would have to be supplied if they are to be considered. Owner's costs that might apply include costs for management of change, revision of records, process safety reviews such as HAZOPs, training, startup and the owner's project team. Some costs, such as procurement and receiving, may be owner's costs on small projects.

In addition to the basis issues already discussed, there is one issue that may or may not be part of the basis, but which the owner may want to decide or approve. In pump services with a pump and a spare, there is a question of whether to use one VFD or two if there is not a set policy. Answering two subsidiary questions about the service will help answer the question.

The first question is: how will the spare pump be started? If it is to be started manually, there will be time to make whatever changes are necessary to the control of the circuit, and a single VFD could be considered. If the spare must be started quickly or automatically, having a VFD on each pump would be favored.

The second question is: what are the consequences of an error or problem

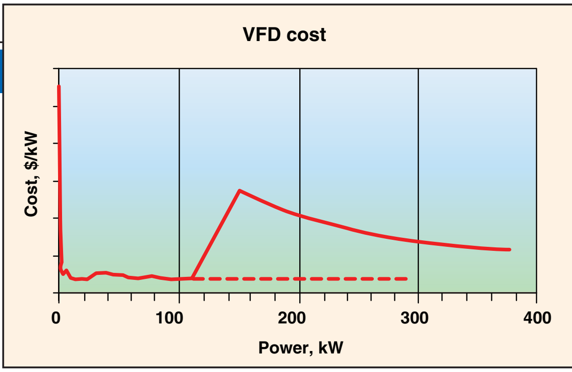

FIGURE 7. The approximate cost of variable frequency drives versus power

TABLE 1.

Differential Capital Costs	
	+ VFD cost
	– Starter cost
	– Control valve station cost
	± Other capital costs
	= Subtotal capital cost
Differential Operating Costs	
	– Power savings
	± Other operating costs
	= Subtotal operating cost
Total Differential Costs	
	Grand Total

in the switch to the other pump (including a failure of the VFD)? If the consequences are minor, such as a temporary increase in power consumption or a spill of water onto the pad, one VFD would be acceptable. If the consequences are not minor, having a VFD on each pump would be favored.

Economic evaluation

Once the basis is set, the economic evaluation is straightforward and is preferably done as the simplest possible analysis, which is a simple payout calculation. This is performed in the manner of a differential analysis considering the case with the control valve to be the base case. The cost of the VFD and any other costs are reduced by the savings for eliminating a separate starter, a control valve station, and any other savings to give the net capital cost. Note that there is little or no installation cost for the VFD but there is an installation cost for the control-valve station and that installation cost needs to be estimated. In the simplest case for a new pump service, which will be used for the development of the approximate evaluation method to be described later, the three specific items mentioned are the only capital cost items that are needed. The sizes required to estimate the costs for these items are available from the process hydraulic calculations for the pump.

The process calculations for the pump will also give the difference between the power required by the base case during the evaluation period and that required by the VFD case. This gives the cost of the power saved, which is the primary operating cost item that is needed to complete the evaluation.

When the cost of the power savings is subtracted from the net capital cost, as summarized in Table 1, the result is the total differential cost. If it is zero or negative, the payout period criterion for the use of a VFD is met.

VFD cost

The first cost item needed is the cost of the VFD; moreover, the variation of VFD costs with power is key to the development of the approximate evaluation method. Single-source budget-grade quotes that are based on a medium-sized project were obtained in mid 2010. They are plotted in Figure 7 as $/kW versus the VFD power, with the scale for the costs omitted to avoid disclosing the exact quotes. The costs were spot-checked for a few sizes in the first quarter of 2012 using a different source and manufacturer. These costs varied from +5% to –25% of the original costs, showing no clear trend and thereby illustrating the approximate nature of the costs. The plot shows three ranges of interest. The first range, where the power is less than 5.5 kW (7.5 hp), is misleading on this plot and will be discussed later.

The range from 5.5 through 110 kW (7.5–150 hp) shows that the cost per kilowatt is nearly constant; there is no economy of scale. The VFDs in this range are low-voltage (480 V for example). Although it is counterintuitive, the nearly constant cost in this range suggests that an approximate evaluation could be performed for low-voltage VFDs independent of their size. The rounded cost in this range is an especially round number of $100/hp in English units ($125/kW). Low-voltage VFDs are manufactured in sizes to at least 375 kW (550 hp), but the maximum power of motors on low-voltage circuits is set by the owner's policy or by the electrical design. It is not available as a parameter for optimization in the evaluation of VFDs. The highest power for a low-voltage VFD in the quotes is 110 kW (150 hp), which is near the lower end of the range at which the switch would be made to medium voltage. Accordingly the cost line for the low-voltage VFDs is shown extrapolated to higher powers as a dashed line in Figure 7. Even ending at 110 kW (150 hp), the low-voltage range covers the greatest number of pump services.

Although there is a smaller number of services requiring medium voltage (for instance, 4,160 V), those services may be more important because there is more cost involved and more power to be saved. The range from 150 kW (200 hp) and higher shows that the cost per kilowatt for medium-voltage VFDs is not constant and that the cost is much higher than the cost of low-voltage VFDs. As a result, the evaluations of medium-voltage VFDs need to be done on a case-by-case basis and do not lend themselves as well to an approximate method. However, their higher costs justify a more thorough evaluation from the start.

For the evaluation of low-voltage VFDs, one needs the net cost of the VFD less the cost of the starter that would not be needed. Figure 8 shows a plot similar to Figure 7 but of this net cost rather than the cost of the VFD alone. The plot shows that the net cost for VFDs of 2.2 kW (3 hp) or less is approximately zero. The cost of the starter is about the same as that of the VFD in this range. At 4 kW (5 hp), the net cost is about half of the cost at 5.5 kW (7.5 hp) and higher. Consequently, it is expected that an evaluation of a VFD at 4 kW (5 hp) or less would meet almost any payout criterion. However, no one would actually perform such an evaluation in this range where the costs are so small; one would just choose the control method that one wanted.

For low-voltage VFDs of 5.5 kW (7.5 hp) and higher, Figure 8 shows that the variability of the net costs is greater than that of the VFDs alone. The trend line, shown dashed, is flat when judged by eye and the variability is almost contained within ±30%

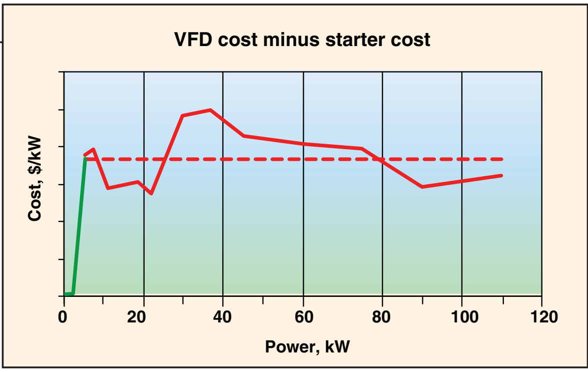

FIGURE 8. The cost of VFDs minus the cost of a starter

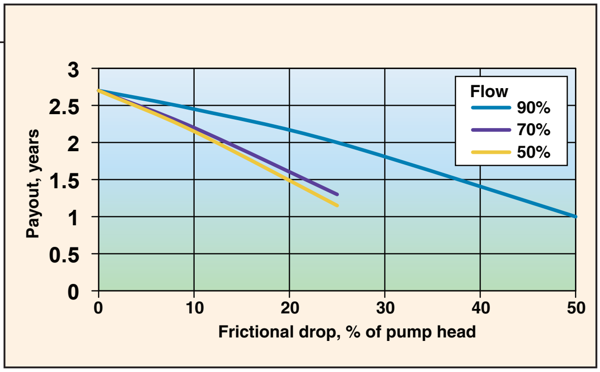

FIGURE 9. The payout time for cases with two pumps and two VFDs

bounds. This is sufficiently accurate for an approximate method.

Approximate evaluation method

There are a number of assumptions and simplifications that apply to the approximate cost evaluation method. The method strictly covers only new installations with low-voltage VFDs. The evaluation will be a differential analysis of a case using a VFD against a base case using a control valve throttling the pump discharge.

- The pump will be a centrifugal pump, has a single service, and operates continuously. This actually describes most pump services in the CPI. Operating the pump at different rates during the evaluation period does not violate the concept of a single service, but either the different rates must be averaged for use in the evaluation, or each rate must be calculated separately. It has previously been mentioned that different flowrates cannot be averaged linearly without losing accuracy. The pump may have more than one circuit with the VFD replacing the control valve in the controlling circuit. A brief operation of the pump at different flowrates, such as might happen at startup or shutdown, does not affect the economics significantly and may be ignored
- A particular set of design criteria is used to set the pressure drop for the control valve at the pump rated capacity. The more conservatively this pressure drop is set, the better a VFD evaluates, and vice versa
- The pump follows the affinity laws
- Pump efficiency is predicted by correlation. The small decline in pump efficiency with reduced pump speed is neglected. For VFD cases with both static and frictional pressure drop, the efficiency is assumed to be proportional to the predicted efficiency at the operating capacity for the fraction that is static drop and the predicted efficiency at the rated capacity for the fraction that is frictional drop
- The same sizes of pump and motor apply to both cases. A correction for having a difference will be discussed later
- An inverter-capable motor will be used in both cases so there is no cost difference
- The same cable and enclosure will be used in both cases or the cost difference will be ignored
- Any difference in the required building space is ignored
- Maintenance costs will be the same in both cases or the cost difference will be ignored
- The engineering costs and owner's costs are assumed to be the same for both cases. More electrical drawings and specifications are required for the VFD, but fewer piping drawings and control valve specifications are needed
- The piping is carbon steel, utilizes 150 psig flanges, and is the same size for both cases. Two methods were available for estimating the piping costs; the method chosen gave the lower costs
- The motor overdesign is 15%
- The base power cost is 7.2¢/kWh
- Instrument air, which is required in the control valve case, is ignored. Other utilities, except power, are assumed to be the same
- The base correlation considers the power consumption to be a constant fraction of the nominal power of the motor. The required power at rated pump capacity including the overdesign (as opposed to the operating power consumption) is set approximately midway between the next lower motor size and the selected motor size. This assumption simplifies the base correlation by eliminating the power consumption as a variable and may be approximately correct as the required power moves across motor sizes, but is not strictly correct. The power consumption as a fraction of the motor power obviously varies as the required power changes within a motor size from just exceeding the power of the next smaller motor to barely being within the power of the selected motor. A correction factor based on the operating power consumption is provided so that the user can refine the base correlation to account for a more-accurate power consumption

The method covers: (a) non-critical services with one pump and one VFD, and (b) critical services with one pump, one spare and two VFDs. It does not cover critical services with one pump, one spare and only one VFD, but this case is between the cases that are covered. The method predicts a simple payout time from two parameters that were shown previously to be significant: the flowrate as a percent of rated capacity and the frictional pressure drop as a percent of the total pressure drop. The frictional pressure drop for this correlation excludes the control valve. The method was developed by calculating cases following the stated assumptions with a spreadsheet and plotting the results. The maximum normal capacity is usually called 100%, and the rated capacity becomes a number above 100%. Here it is more convenient to call the rated capacity 100% and state the other rates as numbers less than 100%. Using this convention, the maximum normal capacity is taken as 90%.

For the non-critical service with one pump and one VFD, the worst case was calculated first; it had an operating capacity of 90% and a frictional pressure drop of 0%. That is, there was no turndown from the maximum normal capacity and the pressure drop was all static drop. The result was a payout period of 0.76 yr or 9.1 mo. This worst case would probably meet any payout criterion, therefore, further cases were not calculated.

For the critical service with two pumps and two VFDs, the results are presented in Figure 9, which shows that any VFD case above 25% frictional drop would have a payout period of 2 yr or less. In the region shown in the figure, the lines are nearly linear but cannot continue to be so toward a zero payout period. A zero payout period would indicate that the base case and the VFD case have equal capital costs. This result is independent of the turndown and the percent of frictional drop. Any case with a capital cost difference to be offset by power savings would need to have a positive payout period regardless of the turndown or the percentage of frictional pressure drop. Anyway, the region of short payout periods does not need be defined accurately because any cases in this region would obviously meet any reasonable payout criterion.

Adjustments

There are many assumptions and simplifications involved in the base evaluation method just presented, but this produces a simple correlation that the process engineer can apply before he or she performs the pump process calculations. He or she needs only to know the capacity as a fraction of the rated capacity and to estimate the percentage of the pressure drop in the pump circuit that is frictional. He or she can have an indication of whether or not a VFD should be shown in early documents, such as the PFD. When the pump process calculations have been completed, some corrections can be applied to refine the estimate:

- The prediction of the payout period can be refined by making a correction for the power required at the normal capacity of the pump in the VFD case rather than accepting the constant percent of the motor power that is built into in the base evaluation. The correction factor is given in Figure 10 where the x-axis (X_W) is the ratio of the operating power at normal capacity for the VFD case to the nominal power of the motor. The correction factor, which can be can be up to ±50% on the payout period, is given below in equation form

$$\text{Correction Factor} = -4.5\, X_W + 4.06 \qquad (12)$$

- A correction may be applied for the cost of power with the payout period being inversely linear with the cost of power. As would be expected, saving more expensive power requires less time to recover the investment than does saving less expensive power. The correction factor is:

$$\text{Correction Factor} = 7.2/PC \qquad (13)$$

Where PC is the cost of power in cents per kilowatt hour (¢/kWh)

- If the service is intermittent, the result is the operating time required for payout, not the calendar time
- The author is not aware of any cost index that would track VFD cost. Besides, the payout period is not a linear function of VFD cost so a simple correction could not be applied. The best procedure may be to use the results of second stage evaluations, which have been done previously, to give a range of overall adjustment factors that include updated costs and also correct for assumptions that do not conform to the policies or design standards being used
- If the use of the VFD allows the elimination of a minimum flow bypass, the capital cost of the VFD case will approach that of the base case. The power saving will be almost entirely a bonus
- If the piping is made of an alloy such as type 316 stainless steel, the capital cost of the VFD case will be approximately the same as that of the base case. The power saving will be almost entirely a bonus
- If the use of the VFD allows the size of the pump or the size of the motor to be reduced, the VFD case will be the minimum capital cost case. The power saving will be entirely a bonus

Even if the corrections help the accuracy, the results are still approximate and must be considered preliminary. However, with a preliminary evaluation, a process engineer can judge whether to proceed with a second stage of evaluation and involve other engineering disciplines. In the second stage the engineer needs to consider those points that might make a significant difference and that are insufficiently accurate, are ignored or are assumed incorrectly in the preliminary evaluation. Conceivably, the preliminary evaluation could be considered final if it is so conclusive that none of the points could change the conclusion. On the other hand, the consideration of how much of a change the various points could make might itself be considered the further evaluation that is required.

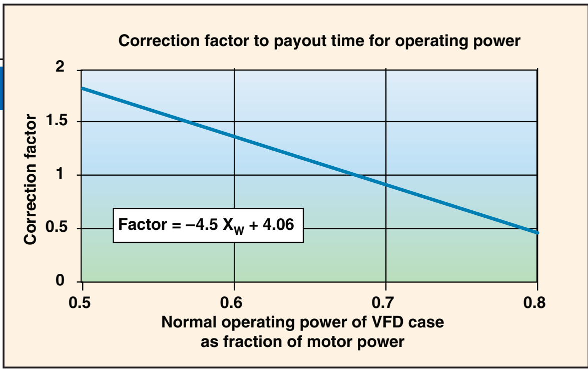

FIGURE 10. A plot of the correction factor to payout time for operating power

An example makes it clear

Use the approximate method to determine if VFDs would be economical for a case with a pump, a spare and two VFDs where the requirement is a simple payout before taxes of 2 yr or less. The frictional pressure drop is 25% of the total pump head for the VFD case, and the operation is at 70% of the rated capacity. The power consumption is 35 kW, and motors of 55 kW (75 hp) have been selected. The cost of power is 7.6 ¢/kWh.

From Figure 9 for 25% frictional pressure drop and 70% capacity, the base payout period is 1.3 yr. The correction factor for power consumption is calculated as follows:

$$X_W = 35\text{ kW}/55\text{ kW} = 0.64.$$

From Equation (12) (or Figure 10):

$$\text{Correction Factor} = -4.5(0.64) + 4.06 = 1.2$$

The correction factor for the cost of

power from Equation (13) is:

Correction Factor = 7.2 ¢/kWh ÷ 7.6 ¢/kWh = 0.95

The corrected payout period is:

Payout = 1.3 yr × 1.2 × 0.95 = 1.5 yr

Since this is less than 2 yr, the preliminary conclusion is that VFDs would be economical and worthy of further evaluation.

Qualitative pros and cons

In addition to the items in the economic evaluation, there are some advantages and disadvantages that are not easy to quantify.

Advantages. First, experience with pumps running at fixed speeds has convinced some firms that, where they are applicable, pumps running at lower speeds require sufficiently less maintenance that their higher capital cost is justified. VFDs control pumps by reducing their speed, so they also reduce the maintenance to the extent that they reduce the speed. Second, VFDs start the pumps at a slow speed and increase it steadily to the required speed. This is a desirable method of starting pumps that minimizes the impact on both the motors and the pumps, and minimizes the wear. Third, the engineering and construction schedule may be shortened a little by eliminating some control-valve stations. The piping design and construction work is usually on the critical path, while the electrical design and construction work may not be. Therefore, reducing some piping work at the expense of increasing some electrical work may improve the schedule.

Disadvantages. There are also two qualitative disadvantages for VFDs, the first of which is a potential piping vibration problem. The piping of a pump running at variable speeds is subject to multiple exciting frequencies and may vibrate at frequencies where the piping of a pump running at a fixed speed would not. Some VFDs can be programmed to skip speed ranges, which may be an easy solution if the pump does not have to operate at the speeds that are causing problems. Otherwise, additional piping support at additional cost will be necessary.

The second disadvantage is that an additional operator may be required for manual operation. A control-valve station will frequently be located near the instrument that is displaying the variable that is being controlled so that a single operator may observe the readout and adjust the control valve or its bypass. A VFD is usually located in a windowless room, which may require that a second operator transmit by telephone or radio the required adjustments to the operator at the VFD. If a mobile data readout is available, and if the problem that is requiring the manual operation does not affect it, a second operator would not be required.

Management of evaluations

Low-voltage VFDs are sufficiently inexpensive that highly detailed evaluations cannot be justified for typical new applications because the engineer or manager would be facing something like an economic version of Heisenberg's uncertainty principle. Attempting to model many cases, to account for the costs of minor items, or to estimate the costs to high accuracy can cost enough, in itself, to alter the results of the evaluation. The methods used and the items considered must be limited to those that are appropriate to the size of the investment being considered.

For example, two 37 kW (50 hp) VFDs would cost approximately $10,000. Allow credits of approximately $2,000 for the starters and $4,000 for the control valve station. If there were no other costs to consider, the net investment would be about $4,000. It would obviously be unwise to spend $4,000, or any significant fraction of it, doing an evaluation. It would be better to spend the money on the VFD. A lot of time cannot be justified to evaluate such small net investments.

Generally, the pump offerings of all vendors will be similar and will also be similar to the engineer's preliminary pump selection because everyone would be thinking alike about the selection. An outlying offering would probably be eliminated in a bid tabulation. However, it is possible that a significantly different offering could be viable or that a usable, surplus pump could be available that is not close to what would be selected new. Shukla and others [*6*] give an example of evaluating multiple options. Such possibilities might require evaluating more than one case, but it would still be necessary to limit the time spent on the evaluation.

Like the cases mentioned above, retrofits may require a more extensive analysis. More items may be involved because items, such as motors or cables may have to be replaced. The associated costs would not offset for retrofits; therefore the evaluations are more complex. This article can serve as a preliminary checklist of items that might contribute cost. The investment is likely to be higher for retrofits, thereby justifying more time for evaluation, but the evaluation must still be limited. Only items that contribute enough cost to affect results should be selected, and they should be evaluated without going into great detail.

Medium-voltage VFDs require a more thorough evaluation. The need to spend very little time in the evaluation, as discussed for low-voltage VFDs, does not apply to medium-voltage VFDs. Also, the approximate evaluation method does not apply to them, although it may be a starting point. Unlike their low-voltage counterparts, medium-voltage VFDs are expensive and will justify a more thorough evaluation.

Although there are the exceptions mentioned, little time can be

rationally devoted to the economic evaluation of low-voltage VFDs. This applies only to the study to choose whether or not to use a VFD; it does not apply to the design itself. That, of course, must be thorough and take whatever time is required. The engineer, the manager and the owner's personnel need to be in agreement on the need to avoid unjustified cost on the economic evaluation. They, like Heisenberg, must be ready to accept some uncertainty. ■

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References

1. Green, Don W., Ed., "Perry's Chemical Engineers' Handbook," 8th Ed., McGraw Hill, New York, pp. 10–24 to 10–39, 2007.
2. Kelly, J. Howard, Understand the Fundamentals of Centrifugal Pumps, *Chem. Eng. Progress*, 106(10), October 2010, pp. 22–28.
3. Rase, Howard F. and Barrow, M. H., "Project Engineering of Process Plants," John Wiley & Sons, New York, pp. 248–296, 1957.
4. Kern, Robert, Practical Piping Design 12 Parts, *Chem. Eng.*, December 23, 1974, through November 10,1975.
5. Crane Company Engineering Division, Technical Paper 410 Flow of Fluids Through Valves, Fittings, and Pipe 13th Printing, Crane Co., New York, 1973.
6. Shulka, D. K., Chaware, D. K. and Swamy, R. B., Variable Frequency Drives: An Algorithm for Selecting VFDs for Centrifugal Pumps, *Chem. Eng.* 117(2), Feb. 2010, pp. 38–43.
7. Shuman, Brian, Building a Reliable VFD System, Belden Document VFDWP, 2009, http://www.belden.com/docs/upload/VFD_Choosing_WP.pdf.
8. Goricke, Bastian and Grunwald, Stefan, Challenges and Requirements in VFD Cable Design, Version 1.1, Lutze, Inc., http://www.emspartnersinc.com/images/VFD_White paper_Lutze_Driveflex.pdf.
9. ABB, ACS550 User's Manual Rev. G, ABB Oy, Helsinki, Finland, July 7, 2009, p. 284.
10. Toshiba, P9 ASD Installation and Operation Manual, Document Number 64054-002, Toshiba International Corp., Industrial Division, Houston, June 2011, p. 20.
11. Eaton Corp., 9000X AF Drives User Manual, MN04001004E / Z10673, Eaton Corp., Cleveland Ohio, May 2011.
12. Burt, Charles, Piao, Xianshu, Gaudi, Franklin, Busch, Bryan and Taufik, N.F.N., Electric Motor Efficiency under Variable Frequencies and Loads, ITRC Report No. R 06-004, Irrigation Training and Research Center, California Polytechnic State University, San Luis Obispo Calif., October 2006, www.itrc.org/reports/vfd/r06004.
13. Rase, Howard F. and Barrow, M. H., *op. cit.*, p. 259.
14. Crane Company, *op. cit.*, p. 3-2

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Anti-surge Valves for Dynamic Compressors

Follow this guidance to improve the selection and sizing of anti-surge valves for axial and centrifugal compressors

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FIGURE 1. This picture shows an example of an anti-surge valve

One of the most significant limitations on the operation of dynamic compressors (axial and centrifugal compressors) is the low-flow limit known as "surge". A sudden valve closing, such as for emergency shutdowns or for a suction/discharge valve, presents significant challenges to anti-surge valve sizing and selection. Anti-surge valve requirements depend to a large degree on the compressor type, the compression system arrangement, and particularly the volume of the discharge piping downstream of the compressor. Important aspects of anti-surge valve sizing and selection for plants in the chemical process industries (CPI), as well as examples, are discussed in this article.

The basics

At low flows, the performance of a dynamic compressor — particularly centrifugal and axial compressors — is limited by the occurrence of aerodynamic flow instabilities that could lead to a catastrophic failure of the compressor due to mechanical or thermal loads. The surge is an unstable flow situation that occurs when the flow is too low. When a dynamic compressor reaches its surge limit, the flow pattern through the compressor collapses, and a sudden backward flow of gas occurs from the discharge to the suction side of the compressor.

This surge phenomenon can cause a reversal of the thrust loads (large dynamic/transient forces on the rotor), which can result in damages to bearings (particularly thrust bearings), seals and other parts of the compressor. For these reasons a surge — and particularly high-energy surges — should be avoided. Recent innovations in control technology, dynamic simulations, rotating machinery knowledge and control-valve design (the anti-surge valve) have made it possible to supply anti-surge systems that are capable of coping with rapid flow fluctuations and process gas variations.

A dynamic compressor, also known as a "turbo-compressor", is generally provided with an anti-surge valve (Figure 1) in order to keep the compressor in a stable operating range. This is achieved by assuring a suction flow that is higher than the corresponding flow at the surge. An anti-surge valve is placed in the anti-surge circuit (a recycle circuit).

The main purpose of this valve is to avoid a surge and surge-related damages, particularly irreparable damages (Figure 2). The anti-surge system and the controller, which comprise both hardware and software, should be based on a design algorithm that operates very quickly when opening the anti-surge (recycle) valve to avoid the surge. However, this anti-surge system should be designed and programmed so as to not make the circuit (or the compression unit) unstable.

Centrifugal and axial compressors experience a surge whenever they are suddenly tripped. Controlling the head and total energy of the surge event, particularly a surge at the trip, is the main objective of dynamic simulations and anti-surge valve sizing and selection. Meaningful gains can be made by a better understanding of the interactions between the compressor, the anti-surge valve(s) and the facility piping and layout (including coolers, scrubbers, check valves, vent valves and more). Key parameters for anti-surge valve selection and sizing include the following: fast response, optimum size, high integrity, accuracy and noise abatement.

The anti-surge valve

The size of an anti-surge valve influences the amount of fluid that can be moved from the discharge side of the compressor to the suction side. Larger valves allow more flow. The speed with which an anti-surge valve opens is also important in rapidly reducing the discharge pressure (the head and stored energy at the compressor discharge). One important trade-off in relation to anti-surge valves is that larger valves exhibit slower opening rates. There are certainly cases when a faster, smaller valve is better than a larger, slower valve, but in all cases, the anti-surge valve should be large enough to handle the flow supplied by the compressor at a sufficiently low differential pressure (head).

Another important factor is controllability. Larger valves are more difficult to control. The faster the valve can be opened, the more flow can pass through it and the more effective it is in surge prevention. There are limits to the valve opening speed, dictated by the need to control intermediate positions of the valve. There are some practical limits to the power of the actuator. The situation may be improved by using a valve that is boosted to open, combining a high opening speed for the surge avoidance with the capability to avoid oscillations.

During a surge event, the flow increases rapidly at first and then decreases more slowly as the pressure difference across the compressor — and consequently the anti-surge valve, too — decreases. With a relatively large anti-surge valve, the energy level at which the surge occurs is much lower compared to a smaller anti-surge valve. An anti-surge valve with a relatively large capacity (compared to the compressor's volumetric flowrate), but with the same opening time (compared to relatively small anti-surge valves), will allow the shutdown surge to be avoided (or the shutdown surge will occur at a lower head condition). On the other hand, a relatively small anti-surge valve could cause a more energetic and more potentially damaging shutdown.

The ability to quantify these effects and select a proper valve size by dynamic modeling can be very useful. Because of this, accurate simulations are encouraged in order to select an anti-surge valve with an optimum size.

The effect of valve flow coefficient. In a case study for a centrifugal compressor in a CPI plant, two anti-surge valves with the same opening time (around one second) were evaluated and compared. The small anti-surge valve resulted in a drop in flowrate without much change in the pressure head. The shutdown surge occurred at a moderately high discharge pressure. The large anti-surge valve — with a valve flow coefficient (C_v) about two times that of the small valve — resulted in a major reduction in the head. The shutdown surge occurred at a discharge pressure just above the suction pressure. The surge event in this case was not even noticeable. The flow reversed through the compressor at a low head point. This case study shows the surge-preventing effects of an anti-surge valve with a higher C_v compared to a smaller valve with a lower C_v.

Additional requirements for anti-surge valves include the following:

1. The reduction of stroke time (in response to control signal step changes)
2. A stable response
3. Minimized overshooting during the valve adjustment steps

The requirements for an anti-surge valve should always be optimized. Too fast a response can result in excessive overshoot and poor accuracy. However, too slow a response could result in sluggish opening of the anti-surge valve and possible inadequate protection of a compressor from a surge. Most information required for the sizing of anti-surge valves is available on the compressor map (the compressor curves). Well-known compressor manufacturers and anti-surge system suppliers have their own standards for the safety margins on anti-surge valve capacity. This figure is usually based on the compression system dynamics, the valve response and the system characteristics.

The anti-surge valve should be capable of passing 100% of the surge flowrate at around 50% of the valve opening. In other words, the anti-surge valve's C_v is selected to be approximately two times that of the required C_v, based on the compressor surge flow on the highest compressor speed curve (on the compressor map).

Valve noise. When the anti-surge valve is opened by the anti-surge system, the valve dissipates a large portion of operating power of the compressor. A portion of the power dissipated by the valve is converted into acoustic energy, which becomes valve noise. Apart from the noise, considerations should also be given to the fluid velocity in the valve outlet. This should be kept within some limits to avoid pipe vibrations. Typically, CPI plants use an anti-surge-valve noise limit range (before the external attenuation) from 85 to 100 dB(A). The anticipated noise level (before the external attenuation) should not exceed 105 dB(A) with fluid velocities below Mach 0.3.

Anti-surge valves should be designed to increase the total system efficiency over a wide range of the operation. The inline and symmetrical flow path eliminates indirect flows and unnecessary changes in the flow directions through the valve. Axial-flow anti-surge valves are most often specified. This design is rugged and offers high performance. It is highly reliable and requires little maintenance. The "breaker vanes" are often used in the downstream section of the valve body (downstream of the valve's flow-control internals), which cut and streamline any flow turbulence. This can result in significant reductions in the noise and the turbulence, eliminating excessive vibrations in the valve and the associated piping, supports and structures.

The anti-surge valve should be capable of changing its position in a short period of time. For reasons of reliability, a spring-loaded actuator is desirable. The typical control instrumentation and accessories provided on an anti-surge valve can include a valve positioner, a volume booster and a solenoid. In other words, usually a solenoid valve with a well-designed booster device (that accelerates the positioner operation) is used.

The correct size and configuration of the required actuators, instrumentation and accessories could guarantee an anti-surge-valve response time of less than 2 s (to fully open). An overshoot on intermediate changes should be kept to an absolute minimum.

Control range. The anti-surge valve should have a wide control range. The whole valve system should operate

FIGURE 2. Axial compressors are very vulnerable to damage from surges. This photo depicts the type of blade damage that can be expected as a result of a surge event in an axial compressor

very quickly in case of an emergency (particularly an emergency-trip surge event). A very high operating rangeability is usually required. Typically, a rangeability of 150:1 is specified. The rangeability parameter is defined as the ratio between the rated C_v for a completely open valve and the minimum C_v that the valve can control. A high rangeability value means successful control even with a high differential pressure and a low flow.

To increase the rangeability, special trims are used where the area distribution is made according to the valve characteristic curve. For example, in some valve designs, until 40% of the stroke, the C_v is typically limited to 15–25% of its maximum value to obtain superior controllability. Too often, a special trim with multiple jumps is specified for an anti-surge valve.

Service reliability. Good service reliability even under very severe conditions (for example, compression ratios lower than 0.3, a discharge pressure ranging up to 600 bars or more, and other difficult situations) is required. In order to obtain these requirements, the following considerations should be respected:

- Anti-surge valves in various trim styles are usually fitted with pressure balanced pistons. The required thrust should be virtually independent of the differential pressure across the valve
- Bushings should be anti-seize and self-lubricated. The internal sliding area requires high-quality and special design and materials (usually chromium-plated internals are specified)
- Proper packings should be used. Typically, a charged polytetrafluoroethylene (PTFE) with a special design is specified. For low molecular-weight gases (such as hydrogen) high-quality graphite packing is commonly specified
- The trim materials should be chosen for good corrosion-proofing and erosion-proofing. For usual services, a proper stainless-steel alloy is typically specified. For a special application, a special, sintered tungsten carbide could be a good selection. The trim design should allow for excellent sealing
- For high-pressure anti-surge valves, additional requirements should be considered. For example, the welded seat is replaced by a high-quality cage seat for superior sealing, better centering and easier maintenance and operation

Leakage. Leaks across an anti-surge valve can influence the efficiency of a compressor system. Even under the most severe working conditions, high-quality anti-surge valves should maintain a tight shut-off (within practical limits) over the full pressure range. With this feature, the compressor efficiency is maintained at the highest levels during the normal operating mode. In a case study for a medium-size high-pressure centrifugal compressor (8-in. ASME Class 900 recycle control valve), with an ASME Class IV leakage rate and a differential pressure of around 70 bars, the valve leaked approximately 150 Nm^3/h of a compressed gas.

The leakage feature should be independent of the actuation method. New designs do not need a higher torque as was required in older designs. In modern designs, the ASME Class IV sealing class is usually achieved by the position and not by the torque. Rapid changes in the differential pressure across the anti-surge valve should have no effect on the stability of the valve position. A fast response is usually achieved with properly sized actuators in contrast to those fitted on conventional control valves. These advanced actuators are usually very efficient and compact. They cannot be bulky or massive. Modern designs contain a minimum number of moving parts and a short valve stroke. These advanced designs permit fast actions and reliable operation.

Various studies, different simulations and extensive operational experiences pertain to a typical "one anti-surge valve, one compressor casing" arrangement. More complex systems of cascaded valves (or valves around multiple compressors) require a more detailed analysis and sophisticated provisions.

Valve and size selection. An anti-surge valve should be sized to meet two diverse objectives: steady-state operation and transient cases.

During steady-state recycling, the required capacity of the anti-surge valve can be directly derived from the compressor map (the compressor curve). Typically, smaller valves exhibit smoother control. During transient conditions, however, the required valve capacity increases. To avoid a surge during an emergency shutdown (or similar transient events, such as a sudden suction or discharge valve closing, or others), a bigger valve will give better performance. To fulfill both above-mentioned requirements, an anti-surge valve with an equal percentage characteristic (defined below) is recommended. Two types of anti-surge valves are generally used: globe valves and ball valves (noise-attenuating ball valves).

The equal percentage characteristic spreads the first half (50%) of the valve's fully open capacity over the first two thirds (66%) of the valve's travel for a globe valve, and about one third (33%) of the valve's fully open capacity over the first two thirds of the valve's travel for a ball valve. An anti-surge valve should be described by its maximum capacity (C_v), and by its capacity as a function of the valve travel, and the opening behavior. The globe valve's C_v approximately varies with the square of the percentage travel. The ball valve's capacity varies roughly with the cube of the percentage travel. A ball valve will have more capacity to depressurize the discharge volume compared to a globe valve of the same size.

In a case study for a 6-in. (150 mm) anti-surge valve, the C_v of a ball valve was more than 2.5 times of the C_v for a same-sized (6-in.) globe valve. At two thirds of valve travel, the ball valve flowrate was more than 50% higher than that for the same-sized globe valve. This additional flow capacity would sometimes, theoretically, make the ball valve a better choice in an anti-surge application. This is particularly true where there is only a single anti-surge valve per stage (for example, there is no hot-gas bypass) and the discharge volumes are large (especially when the anti-surge loop is taken from downstream of the discharge cooler). However, this is just a theoretical and textbook idea.

From a practical standpoint, the globe valve behavior is more predictable. The globe valve is more comfortable to control and manage. It is relatively less nonlinear. The ball valve usually offers a highly nonlinear behavior (C_v varies with the cube of the percentage of travel).

The anti-surge valve should be matched to the compressor system. Both globe and ball valves are used in modern anti-surge systems (depending on the application). Practically, a globe valve is more common in anti-surge systems.

In some compressor installations, it is necessary to have both a normal anti-surge valve (the recycle line taken from downstream of the after-cooler or the anti-surge line that includes a cooler) and a hot-gas bypass valve, which can be opened to rapidly transfer the compressed gas back to the suction side of the compressor without cooling (usually for a short period of time). A hot-gas-bypass allows the pressure head across a compressor to be rapidly reduced during a trip. Various options for anti-surge valve size, opening rate, recycle loop arrangement and operation sequence should be evaluated. Parametric studies of the anti-surge valve size and opening time can yield optimum sizes for an anti-surge valve (and a hot-gas-bypass valve, if required).

Overheating. A large portion of the mechanical energy produced by a compressor is converted into heat in the discharged gas. In an uncooled recycle-loop system, this heat is recycled into the compressor suction end, and then more heat energy is added to the recycling gas. In a typical natural-gas centrifugal compressor at a 100% recycle without recycle cooling, the temperature of the gas increases about 1°C per second. Eventually, this could lead to overheating at the compressor discharge side.

In theory, the recycling can lead to heating whenever the compressed gas cannot be cooled to the initial operating temperature at the compressor suction side. This is the case both for a hot-gas bypass and a partially cooled bypass (if the cooled bypass is not designed properly, for example, when sufficient cooling capacity is not provided). The overheating could be defined as the gas temperature within the compressor exceeding 150–190°C, depending on the process. The same problem may also occur if there is a long period of time between the start of rotation (the compressor startup) and overcoming the pressure downstream of the discharge check valve, when some kind of hot-gas bypass is used for the startup.

Control and testing

An anti-surge-system configuration usually allows an operator to open the anti-surge valve further than the valve position that is defined by the anti-surge controller (based on the algorithm) in manual-mode operation. However, the operator cannot close the anti-surge valve any further than the surge controller permits. The controller can override the manual mode, if necessary, to open the anti-surge valve. The "fail safe" philosophy that is commonly employed is that the anti-surge valve should be an "air-to-close" valve (fails open). The control is used to force the anti-surge valve fully open whenever the compressor is shutdown. This helps to prevent a surge on a compressor shutdown, and also holds the anti-surge valve in a fully open position for a startup.

Extreme care has to be taken when testing an anti-surge system during operation. The compressor should not accidentally be pushed into a surge. The controller should take over if something causes the operating point to head toward a surge. Such features should be available, enabled and working correctly. A sudden movement of the anti-surge valve could have an adverse impact on the remaining gas system (the upstream and the downstream of the compressor). All of these control actions should be evaluated properly.

It could be useful to assess how the anti-surge valve behaves in response to a small 1–2% change in the command signal. Bad signs are hunting, stiction (the static friction that needs to be overcome when the anti-surge valve-position should be changed), hysteresis and delayed lifting, all of which could make the control more difficult.

The anti-surge step test should be performed with the controller in the manual mode and with the valve off its seat, preferably somewhere between 15–85% open. The compressor will be on partial-recycle throughout the test (the remaining process should be able to cope). The first valve step could probably be in the open direction so as to move the compressor further from the surge. If the response is unknown, a small valve movement (even typically 1–2%) should be selected.

One important consideration when operating in the recycle mode is that the gas could thin out due to loss of the heavier components. The surge line of the lower molecular-weight gas may be rather different from the normal gas. Some amounts of new gas should always be fed through the compressor. Another useful test is to introduce a disturbance to the compressor, such as cutting back the suction throttle valve slightly or changing the driver speed (if it is a variable-speed compressor train). It should be verified that the anti-surge valve changes position without any delay and also without a significant undershoot of the setpoint.

Examples

Example 1. The first example is presented for a two-process-stage centrifugal compressor. The two process stages are low pressure (LP) and high pressure (HP). The compressor is a variable-speed synchronous electric-motor-driven unit (using gears) to compress natural gas from around 10 barg to approximately 100 barg. Each compressor stage has an anti-surge valve.

The calculated C_v for the LP and HP compressor casings (at the surge flow of the high-speed curve) are 215 and 81, respectively. The selected anti-surge valve's C_v values for the LP and HP stages are 385 and 169, respectively. In other words, the C_v factors (the anti-surge valve C_v / the calculated C_v at the high-speed surge flow) are approximately 1.79 and 2.09 for the LP and HP loops, respectively.

The selected anti-surge valves are globe valves. The opening time is 2 s and the closing time is 5 s. The valves were purchased with a NACE (National Association of Corrosion Engineers)-compliant carbon-steel body, a stainless-steel (grade 17-4-PH) trim and special PTFE packing. Grade 17-4-PH stainless steel is a precipitation hardened (a chromium-copper precipitation hardened) stainless steel, employed for applications requiring high-strength and a high level of corrosion resistance.

Example 2. The second example is presented for a petroleum-refinery type hydrogen-service centrifugal compressor. It is a steam-turbine-driven, hydrogen-recycle centrifugal compressor for a hydrocracker unit to compress the hydrogen from around 140 to 190 barg. The calculated C_v for the surge point at the high-speed curve (on the compressor map) is 179. The recommended range for the anti-surge C_v is 1.7–2.1 times the calculated C_v for the maximum-speed surge flow. Applying the 1.7 factor (the minimum factor) results in an anti-surge valve C_v above 305.

The selected anti-surge valve is an 8-in. globe valve, 1500# class, RTJ (ring type joint) facing, with a C_v of 308, an opening time of 2 s and a closing time of 6 s. The anti-surge valve was selected with a carbon-steel body (a NACE grade), a stainless-steel (grade 17-4-PH) trim and a special graphite packing. Since the compressor train inertia is low (it is a steam-turbine, direct-driven compressor train), the anti-surge loop is taken from the immediate downstream of the compressor (upstream of the cooler).

Based on experience, for a compressor configuration like this, a relatively low C_v (around or lower than 1.7) is sometimes specified by vendors. Some vendors used C_v factors (the anti-surge valve C_v divided by the calculated C_v at the high-speed surge flow) even as low as 1.55 or 1.6 to keep the anti-surge valve size small. This is not recommended, however, since a sufficiently large anti-surge valve is necessary to handle emergency rapid shutdown situations and unscheduled trips at uncommon (off-design) operating cases.

In other words, 1.7 is the minimum acceptable factor. This hydrogen compressor train is expected to compress nitrogen during the initial startup of the unit. The calculated C_v for the nitrogen operation (the surge flow at the high-speed curve) is around 260. In other words, a surge could be expected in case of an unscheduled rapid trip during the operation with the nitrogen, if a small anti-surge valve is selected. ■

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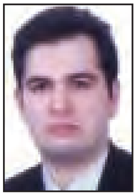
Author



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Designing Chemical-Injection Systems

Mohammad Toghraei
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Follow these guidelines to properly introduce various additives into process streams

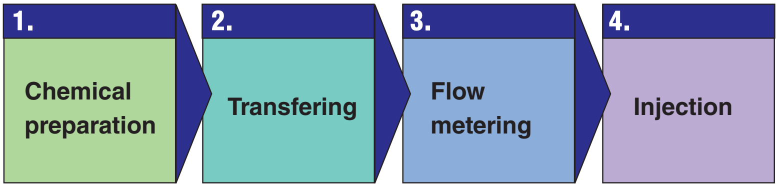

FIGURE 1. Careful attention to each of these steps will help to ensure predictable performance from any chemical-injection system

Throughout the chemical process industries (CPI), various chemicals must be injected into process streams to serve a variety of purposes. Chemical-injection systems can be arbitrarily defined as those systems that are used to inject chemicals at a flowrate that is less than 1 to 5% of the main process stream. Table 1 shows a non-inclusive list of chemicals that are typically added into process streams via injection.

Chemical-injection systems are often overlooked during the design and operation of the overall system. A typical chemical-injection system involves the steps shown in Figure 1.

The following eight points should be considered when designing a chemical-injection system; each is discussed:

1. Choosing the right chemical
2. Choosing the appropriate storage system
3. Ensuring correct preparation of the stream to be injected
4. Choosing an appropriate injection system
5. Determining the right dosage
6. Verifying the injection dosage
7. Determining the ideal injection point
8. Choosing the most appropriate injection tool

1. Choosing the right chemical. The most suitable chemical for a specific application is selected based on published information (books, magazines, websites and so on), previous experience in similar industries, or in-house testing. To minimize the cost, maximum effort should be made to use commodity, non-proprietary chemicals, if possible.

Commodity-type chemicals are typically the least-expensive type of chemicals. Proprietary chemicals may be produced by a limited number of producers and are thus more expensive. The use of these chemicals can be justified if they are highly effective in the application and are tailored for a specific application. Proprietary chemicals typically have complicated compositions, and each composition and its concentration is selected precisely to satisfy specific requirements.

One important aspect of selecting the right chemicals is to consider their fate. Because injecting any chemical into any process system can be looked at as introducing an impurity into the system, the lifecycle of this added "impurity" must be tracked precisely. For instance, will the chemical be consumed completely?

The answer generally is no. This is because the chemical is often injected at an amount that is in excess of the stoichiometric requirement, to ensure the completion of the reaction. This is especially the case also when a chemical is injected for a physical effect. Therefore, there will always be residual chemicals in the system.

Users must consider the following questions when deciding which chemical to use:

- Is it acceptable to have this chemical in the final product, even in trace amounts?
- Will the presence of the chemical be harmful for downstream equipment and media, such as resins, catalyst or filtering media?
- Could the presence of the chemical lead to the deactivation of some catalyst in downstream steps?
- Will the chemical accumulate in the system and foul, scale or plug downstream equipment?

By way of example, using cobalt-catalyzed sodium-bisulphite solution as the oxygen scavenger in produced waters (for instance, those produced during oil-extraction activities) that contain some concentrations of H_2S is not beneficial, because cobalt will be deactivated quickly by the H_2S.

The chosen chemicals could be in solution (or in liquid, gas or solid or powder form). The best options are liquid and solution forms, because they require the simplest and least-expensive injection systems. Injection systems that are required for powders or solid systems are dirty and operator-intensive, especially if they generate a slurry rather than real solutions. In comparing liquids and solutions, liquids tend to be easier to handle, because the buyer pays only for the pure reagent, and not for the solvent that is often required for solutions. However, the pure liquid is not always available.

Gas-injection systems could be the most expensive types of injection systems. They are only justifiable if they have demonstrable economic benefits. One widely used gas-injection opera-

TABLE 1. COMMONLY USED ADDITIVES	
Class name	Examples
Interface adjusters	Emulsion breakers, defoamers, coagulants
Corrosion inhibitors	Filming amines, neutralizing amines
Solid-settling aids	Flocculants, dewatering aids
Precipitation inhibitors	Anti-foulants, antiscalants
Scavengers	Oxygen scavengers, H_2S scavengers
Encapsulators	Chelating agents
Biocides	Chlorine

tion is chlorination, which is practiced during water-treatment operation.

2. Choosing appropriate storage. Proper storage of chemicals is important. Unsuitable storage can result in degradation and loss of the chemicals. For instance, some chemicals may vaporize over an extended period if not properly stored. For example, sulfite-type oxygen scavengers will be lost in non-blanketed storage tanks (due to reactions with the oxygen in air). Since their primary function is to remove oxygen, oxygen scavengers can start their "duty" during their residence in storage tanks.

The other example is the deterioration of hydrogen peroxide in the vicinity of iron impurities (in this case, iron works as a catalyst to accelerate the degradation of hydrogen peroxide). In the majority of cases, any deterioration of chemicals over time is irreversible. Meanwhile, every chemical has its own specific shelf life. This shelf life is a function of temperature, pressure, container material, contact atmosphere, any impurities and the chemical concentration.

Usually, chemicals have a longer shelf time when they are stored at lower (but not freezing) temperatures. In many cases, chemicals that are stored within a suitable temperature range but experience periodic temperature fluctuations will experience decreased shelf time.

Pressure does not have a direct impact on the shelf life of liquid chemicals.

During system design, the compatibility of the storage vessel and the process additive must be checked with the chemical producer to make sure there are not issues that could impact the chemical's shelf life. It is especially important to have a knowledge of the impurities that are present in the chemicals, and the impurities in the materials of construction, as these can react with each other or work as a catalyst to promote a deteriorating reaction.

The least expensive option for chemical storage is an atmospheric tank or vessel, but sometimes the presence of air in the headspace of the container is detrimental for the chemical. And it is not only oxygen and nitrogen in the air that could be detrimental; the potential impact of other small components in the head space air should also be considered. For example, CO_2 is not a negligible component in the air that may be inside of the storage tank or vessel, especially in urban or industrial areas. CO_2 can react with "basic" solutions, such as caustic soda, and decrease the active agent of the solution.

Meanwhile, other low-concentration pollutants in air can be harmful for some chemicals, and this should also be considered. If air is not allowed to be in contact with chemicals, then the storage tank may need to be blanketed with an inert gas, such as nitrogen.

Many of the most widely injected proprietary chemicals are some type of polymer. Generally, polymers have a longer shelf life in higher concentrations. Also, chemical consumers often like to buy chemicals in more-concentrated forms, to decrease the cost of transportation and storage of chemical additives.

Therefore, chemical producers usually market their chemicals based on the highest obtainable concentration. This "concentration ceiling" is determined by a variety of factors. For example, the maximum concentration of hydrochloric acid is about 38%, because concentrations greater that that increase the vapor pressure of the solution and would thus require specific precautions for transportation. The maximum concentration for caustic soda is about 50%, as this is the maximum attainable concentration available in the caustic producing plant without drying systems.

Another decision that must be made for chemical storage is the volume of the storage container. The first step for this decision is to assume a specific storing duration. Factors that will impact this include the delivery time and consumption of the chemical. The former is a function of the availability of the chemical in the vicinity of the plant, or the distance between the chemical producer and the plant location. One guideline in Table 2 proposes conservative storage volumes, as a function of three parameters.

By way of example, consider a chemical that is less critical (so without it, the plant will not need to halt production. Such an additive is called a non-interruptible chemical). In this example, the usage requirement of this chemical is 0.7 m^3/h, it has a 7-d delivery and shipping period (from the time of the request to the arrival of the shipment), and it is delivered by a 25 m^3 truck. Using this information, the following equation will indicate the required storage capacity:

$A = [10\ d \times (0.7\ m^3/h \times 24\ h/d)]$

$B = [(1.5 \times 7\ d/delivery) \times (0.7\ m^3/h \times 24\ h/d)]$

$C = 25\ m^3$

And $A+B+C = 369\ m^3$

Another decision that should be made is to determine whether the chemical should be stored in shop- or field-fabricated tanks, or whether it can be stored in tote tanks. Tote tanks generally can only hold a volume between 1 and 1.5 m^3.

Usually if the consumption of the chemical is relatively low, it can be stored in tote tanks. However, the available room to keep the tote tanks in a plant should be checked. As a rule of thumb: if the overall required storage volume is less than 8 to 10 m^3, then the use of tote tanks makes sense.

As it can be seen, the required flowrate for a chemical is determined by multiplying the dosage and the destination flowrate. Typically, three possible dosage rates (minimum, normal and maximum) and three possible destination flowrates (mininum, normal and maximum, designated as Q_{min}, Q_{normal} and Q_{max}) are most commonly defined, the question is which combination of of dosage and flowrate should be chosen to estimate the most reliable storage volume. For this purpose, operators often multiply the maximum dosage by the average flowrate. The three destination flowrates are chosen in a way that ensures the injection system covers all of the possible operating scenaros.

Q_{max} is considered to be 1.5 to 2 times the normal flowrate. From the other side, chemical-injection systems are one of the few process systems that are expected to be fully accurate even during the startup. Because of this, Q_{min} is usually taken as 25% of the normal flowrate.

When there is more than one usage for a given chemical in a plant, there is always the chance of offloading to the wrong tank, or connecting the wrong chemical tote tank to the injection system. This can be prevented by the use of suitable signage or by using purposefully incompatible hardware that can prevent any unintended chemical flow.

3. Correct preparation. In most cases, chemicals are transported to the process plant in a concentrated solution or powder form. Therefore, the most popular chemical-preparation system involves a dilution system. Two issues should be considered in this regard: the first is whether the viscosity of a chemical is suitable for the selected pump, and the second is whether the diluted chemical has experienced enough aging time.

The issue of sufficient aging, for both dilution and solution formation, is generally applicable to polymer-based chemicals. Polymers (with their chain of atoms) are usually "cramped" in concentrated form. To be most effective, a chemical polymer must be in its "un-cramped" molecular form.

Thus, a specific amount of time should be given for the diluted polymer to settle slowly into its un-cramped form. Severe agitation cannot accelerate this process, and may be detrimental for polymers, especially those with long chains (such as flocculants). This goes against the general practice that usually involves severe mixing for better chemical mixing. Therefore, the mixing of polymeric chemicals should be done more gently, with the impeller tip speed limited to avoid polymer chain breakage.

When there is a need for two-stage dilution (that is, aging, followed by dilution), the system could be designed as a two-container system, using batch operations or a vessel-in-vessel system with continuous overflow.

4. Choosing the appropriate injection system. The injection pump capacity is usually calculated by multiplying Q_{max} by the maximum dosage. The idea is to choose a system that can inject the chemical at a specific flowrate with sufficient accuracy across a wide range of potential destination flowrates. This means that the injection system should have enough precision and good accuracy. A good injecting pump can satisfy the precision requirements, while an appropriate control system guarantees quick pacing of the destination flow, which dictates the accuracy of the system.

Usually, injection systems possess a capacity of less than 5 m^3/h (but sometimes up to 10 m^3/h). The required accuracy is usually better than 1–2%. The only process parameter that a chemical injection system needs to monitor and follow accurately is the flowrate of the injected stream. To satisfy the required precision, a positive-displacement pump (PD) is often used. PD pumps with high accuracy are called metering or dosing pumps. The most popular types of dosing pumps are piston, plunger and diaphragm pumps. A gravity-flow pump or centrifugal pump usually cannot meet the required accuracy for chemical-injection systems.

When setting up injection piping, a dedicated pipe should be used for each injection pump. Using a shared injection pump for more than one injection point is not a good practice, as it may result in variable flowrates of different chemical streams to different destinations. This goes against the main objective of an injection system, which is to deliver specific (and accurate) flowrates at the desired injection point.

When using PD pumps, it is critical to use a pressure safety valve (PSV) at the discharge side of the pump. Usually a back-pressure regulator is placed at the discharge side of the pump to ensure that the injection system delivers an accurate specified flowrate in all cases, even when there is fluctuation in destination pressure.

If the system does not have a back-pressure regulator, the occurrence of instantaneous, very-low pressure at the injection point could cause an unknown flowrate at the destination. The use of a back-pressure regulator is especially critical if the discharge pipe has a backward U shape in its route to the destination point (for example, if the injection pipe goes over the pipe rack).

To satisfy the required precision of the system, the injection pump should be able to accommodate almost every flowrate below its capacity. For example, if the design capacity of an injection pump is 1,000 L/h, it can be expected that this pump can provide an accurate flowrate from 1,000 L/h down to possibly 10 L/h. This can be done by adding a variable-speed device (VSD) to the electric motor of the pump or stroke-adjustment system. The stroke-adjustment system can be operated either manually or via a servo-mechanism. Variable-frequency devices (VFDs) are one popular type of VSD.

To satisfy the accuracy requirements of the chemical-injection system, users need to make sure that the injection system follows the process flowrate over its entire turndown ratio very quickly. To ensure such swift responsiveness, the injection system needs a good control system. A combined feedback/feedforward control system is the ideal choice for complicated cases such as acid-injection situations. The feedforward portion of the control system is a ratio control system that forces the chemical flowrate to follow the destination flowrate. The feedback portion is a control loop that is governed by a property in the resultant stream. The control system can order the VFD or automatic stroke-adjustment mechanism (or both in a split-range control system).

For less complicated cases, a simple feedback control would be sufficient.

For the purpose of pump sizing, the decision on the capacity of the dosing pump is critical. To make sure that the dosing pump can handle all the situations, Q_{max} times maximum dosage is typically used to define the most appropriate capacity for the dosing pump.

5. Determining the right dosage. The reported dosage of a specific chem-

		Interruptible	Non-interruptible
A	Minimum stock to be maintained, days	30	10
B	Allowance to compensate delivery duration (*t*), days	2*t*	1.5*t*
C	Allowance to make sure the shipment can be off-loaded completely	Maximum shipment size	

TABLE 2. PARAMETERS INVOLVED IN CHEMICAL-STORAGE CALCULATIONS

Source: Hudson, Jr., Herbert E., "Water Clarification Processes, Practical Design and Evaluation," Van Nostrand Reinhold Co., 1981, p. 250.

Notes: Interruptible chemicals are those without which there could be an interruption in plant operations; Non-interruptible chemicals are those that are less critical, so their absence does not necessarily interrupt plant operation or product quality.

ical to be added to a process stream is usually a range, but the exact dosage required for a given process stream is a site-specific number. In many cases, the right dosage is determined by some kind of simulation (such as a jar test) carried out in the laboratory. However, if this measured dosage happens to be outside of the published range, it should be taken cautiously. For example, if this dosage is bigger than the highest end of the range, it could indicate that the chemical may not be suitable for that application. If the measured dosage is below the lowest range of the industry- accepted range, then possibly its high effectiveness is already reflected in its price. If this chemical is not more expensive than others, the case should be examined.

Overfeeding and underfeeding should be avoided, if possible. As a general statement, overfeeding creates waste and worsens the impact of residual chemicals in the system, while underfeeding reduces the efficacy of the additive. In some cases, both the overfeeding and underfeeding of the additive make the injection ineffective (this is the case for the injection of coagulants).

6. Verifying the injection dosage. The most popular way to verify the amount of injection is to use a drawdown calibration column. In addition to all provisions to make sure the right dosage is injected to the system, the system also needs to verify the injection flowrate using an accurate method. The verification method usually uses a manual procedure rather than a flowmeter to avoid any inaccuracy. In the verification process using the manual method, the volume of the injected chemical is measured at a specific time. By having these two parameters, volume and time, the flowrate can be calculated.

7. Determining the injection point. Generally speaking, by injecting a chemical two things happen: The chemical will be mixed with the destination fluid, and the chemical can be reacted with the destination fluid. All injected chemicals need mixing to blend them with the process stream, but not all of them will undergo reactions with that stream. In reality, both of these phenomena start to happen at the same time. To be effective, a chemical should be injected far enough from the point of interest to make sure the mixing and reaction can both go to completion. When there are multiple injection locations and the chemicals are reactive to each other, they should be separated by at least 3–5 min to ensure they have enough time to react with the destination flow and not with each other.

8. Choosing the appropriate injection tool. An injected chemical may experience either mixing or reaction, or both, in the process stream without any extra provision in the system. However, it can be challenging to achieve good mixing. The primary form of mixing injected chemicals with the main stream is via jet mixing — either coaxial jet mixing or side-entry jet mixing — in the pipe. Side-entry jet mixing uses a T-shape fitting, which brings the injected chemical to the main stream from the body of the main pipe. Of the two jet mixing methods, side-entry jet mixing is not very popular in chemical injection systems, because it is only suitable when two streams (the injected additive and the main stream), have roughly the same flowrate, density, and viscosity. However, these conditions are not common for the majority of chemical injection systems.

Coaxial jet mixing is often called "injection by quills." If the viscosity of the chemical is below 50 cP, the use of injection quills might be sufficient to ensure good mixing. However, for higher-viscosity chemicals, a static mixer might be needed downstream of the injection quill. If injection is carried out using quills, but there is no static mixer in use, then a mixing length of less than 100 times the destination pipe diameter is expected.

For large pipe sizes, a simple injection quill cannot guarantee good mixing within 100 pipe diameters. In such cases, a multiple orifice diffuser is used instead of quill. As a rough rule of thumb, for destination pipes with diameters larger than 22 in., multiple orifice diffusers should be used. ■

Edited by Suzanne Shelley

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

My personal physician looks at me like I am a distillation column. Dr. Dianne English worked as a chemical engineer for about five years before attending and completing medical school. As an engineer, she worked for Champlin and Conoco-Phillips — and visited some of the same processing units that I did early during my career. Our conversations are in a language that chemical engineers only half understand, and that nurses only half understand. In fact, our conversations are so unsettling to nurses that they sometimes leave the examining room — pretending to be needed at some non-existent emergencies.

Dr. English calls me in for examinations about every six months; she calls them "troubleshoots." Her examination room contains human body PFD's. I offered her an FRI distillation unit PFD, but she thought I was kidding.

She believes that mass must balance. If I eat too much, and if I ride my bike too little, I accumulate mass. She also believes in heat balances. When I accumulate heat, it shows up as a fever. 37°C is my temperature target (98.6°F for the U.S. readers).

My heart is the reflux pump. My blood is the reflux. Blood carries oxygen. Reflux carries clean light compounds. Valves seem to be everywhere — in the heart, in the circulatory system and all across the distillation unit. As of now, all of my personal valves are the ones I was born with. If Dr. English ever tries to replace my aortic valve with a pig valve, I will test the pig valve in the FRI reflux line first.

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After my most recent physical examination, I asked Dr. English a question that was on my mind since the first time I met her in 2008, "Are distillation columns girls or boys?" After due deliberation, she answered, "Distillation columns can be difficult, temperamental, perplexing and unpredictable — they must be boys!" ■

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JOB FUNCTION

20 Corporate Management
21 Plant Operations incl. Maintenance
22 Engineering
23 Research & Development
24 Safety & Environmental
26 Other____________

EMPLOYEE SIZE

28 Less than 10 Employees
29 10 to 49 Employees
30 50 to 99 Employees
31 100 to 249 Employees
32 250 to 499 Employees
33 500 to 999 Employees
34 1,000 or more Employees

YOU RECOMMEND, SPECIFY, PURCHASE
(please circle all that apply)

40 Drying Equipment
41 Filtration/Separation Equipment
42 Heat Transfer/Energy Conservation Equipment
43 Instrumentation & Control Systems
44 Mixing, Blending Equipment
45 Motors, Motor Controls
46 Piping, Tubing, Fittings
47 Pollution Control Equipment & Systems
48 Pumps
49 Safety Equipment & Services
50 Size Reduction & Agglomeration Equipment
51 Solids Handling Equipment
52 Tanks, Vessels, Reactors
53 Valves
54 Engineering Computers/Software/Peripherals
55 Water Treatment Chemicals & Equipment
56 Hazardous Waste Management Systems
57 Chemicals & Raw Materials
58 Materials of Construction
59 Compressors

1	16	31	46	61	76	91	106	121	136	151	166	181	196	211	226	241	256	271	286	301	316	331	346	361	376	391	406	421	436	451	466	481	496	511	526	541	556	571	586
2	17	32	47	62	77	92	107	122	137	152	167	182	197	212	227	242	257	272	287	302	317	332	347	362	377	392	407	422	437	452	467	482	497	512	527	542	557	572	587
3	18	33	48	63	78	93	108	123	138	153	168	183	198	213	228	243	258	273	288	303	318	333	348	363	378	393	408	423	438	453	468	483	498	513	528	543	558	573	588
4	19	34	49	64	79	94	109	124	139	154	169	184	199	214	229	244	259	274	289	304	319	334	349	364	379	394	409	424	439	454	469	484	499	514	529	544	559	574	589
5	20	35	50	65	80	95	110	125	140	155	170	185	200	215	230	245	260	275	290	305	320	335	350	365	380	395	410	425	440	455	470	485	500	515	530	545	560	575	590
6	21	36	51	66	81	96	111	126	141	156	171	186	201	216	231	246	261	276	291	306	321	336	351	366	381	396	411	426	441	456	471	486	501	516	531	546	561	576	591
7	22	37	52	67	82	97	112	127	142	157	172	187	202	217	232	247	262	277	292	307	322	337	352	367	382	397	412	427	442	457	472	487	502	517	532	547	562	577	592
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13	28	43	58	73	88	103	118	133	148	163	178	193	208	223	238	253	268	283	298	313	328	343	358	373	388	403	418	433	448	463	478	493	508	523	538	553	568	583	598
14	29	44	59	74	89	104	119	134	149	164	179	194	209	224	239	254	269	284	299	314	329	344	359	374	389	404	419	434	449	464	479	494	509	524	539	554	569	584	599
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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* International Edition

See bottom of next page for advertising sales representatives' contact information

Classified Index November 2012

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OCTOBER WHO'S WHO


Hensley


Gibbs


Carr


Roderick


Powell

Charles Kraft becomes vice president of global manufacturing and process development for **Amyris** (Emeryville, Calif.), a renewable-chemicals maker.

Intelligrated (Cincinnati, Ohio), a provider of materials-handling solutions, names *Paul Hensley* senior sales engineer for the company's central regional operations.

Avantes (Apeldoorn, the Netherlands), a provider of spectroscopy solutions, appoints *Robert Hukshorn* director of sales and marketing.

Pieralisi Group (Jesi, Italy), a maker of extraction technologies, names *Choi Au-Yeung* to head the separation solutions division.

Strongwell Corp. (Bristol, Va.), a maker of fiber-reinforced polymer composites, promotes *David Gibbs* to vice president, sales and engineering, and *Mike Carr* to director of sales.

Scott Thomson becomes senior vice president in charge of the pharma ingredients and services business unit of **BASF** (Florham Park, N.J.).

Roger-Marc Nicoud, founder and CEO of **Novasep Synthesis** (Pompey, France), a provider of purification solutions for life sciences industries, becomes chairman of the board. *Patrick Glaser* becomes president and CEO.

Westinghouse Electric Corp. (Pittsburgh, Pa.) names *Danny Roderick* president and CEO.

Jim Powell becomes executive director of the **Air & Waste Management Assn.** (Pittsburgh, Pa.). ■

Suzanne Shelley

Statement of Ownership, Management, and Circulation (Requester Publications Only)
1. Publication Title: Chemical Engineering 2. Publication Number: 0009-2460 3. Filing Date: 10/4/12 4. Issue Frequency: Monthly with an additional issue in October 5. Number of Issues Published Annually: 13 6. Annual Subscription Price $149.97. Complete Mailing Address of Known Office of Publication: Access Intelligence, 4 Choke Cherry Road, 2nd Floor, Rockville, MD 20850-4024 Contact: George Severine Telephone: 301-354-1706 8. Complete Mailing Address of Headquarters or General Business Office Publisher: Access Intelligence, LLC, 4 Choke Cherry Road, 2nd Floor, Rockville, MD 20850-4024 9. Full Names and Complete Mailing Addresses of Publisher, Editor, and Maging Editor: Publisher: Brian Nessen, 4 Choke Cherry Road, 2nd Floor, Rockville, MD 20850-4024 Editor: Rebekkah J. Marshall, 4 Choke Cherry Road, 2nd Floor, Rockville, MD 20850-4024 Managing Editor: Dorothy Lozowski, 4 Choke Cherry Road, 2nd Floor, Rockville, MD 20850-4024 10. Owner if the publication is owned by a corporation, give the name and address of the corporation immediately followed by the names and addresses of all stockholders owning or holding 1 percent or more of the total amount of stock: Veronis Suhler Stevenson, 55 East 52nd Street, 33rd Floor, New York, NY 10055 11. Known Bondholders, Mortgagees, and Other Security Holders Owning or Holding 1 Percent or More of Total Amount of Bonds, Mortgages, or other Securities: None 12. Non-profit organization: not applicable. 13. Publication: Chemical Engineering 14. Issue Date for Circulation Data: September 2012.

15. Extent and Nature of Circulation:	Average No. of Copies Each Issue During Preceding 12 Months	No. Copies of Single issue Nearest to Filing Date
a. Total Number of Copies (Net press run)	35,682	35,326
b. Legitimate Paid and/or Requested Distribution		
(1) Outside County Paid/Requested Mail Subscriptions	29,196	28,645
(2) Inside County Paid/Requested Mail Subscriptions	0	0
(3) Sales Through Dealers and Carriers, Street Vendors, Counter Sales or Other Paid or Requested Distribution Outside USPS	3,883	3,901
(4) Requested Copies Distributed by Other Mail Classes	124	107
c. Total Paid and/or Requested Circulation	33,203	32,653
d. Nonrequested Distribution (By Mail and Outside the Mail)		
(1) Outside County Nonrequested Copies	896	803
(2) Inside-County Nonrequested Copies	0	0
(3) Nonrequested Copies Distributed Through the USP by Other Classes of Mail	0	0
(4) Nonrequested Copies Distributed Outside the Mail (Include Pickup Stands, Trade Shows, Showrooms and Other Sources)	694	806
e. Total Norequested Distribution	1,590	1,609
f. Total Distribution (Sum of 15c and 15e)	34,793	34,262
g. Copies not Distributed (Office, Returns, Spoilage, Unused)	889	1,064
h. Total (Sum of 15f and g)	35,682	35,326
i. Percent Paid and/or Requested Circulation	95.48%	95.30%

16. Publication of Statement of Ownership for a Requester Publication is required and will be printed in the November 2012 issue of this publication
17. Signature of Owner: Don Pazour Date: 10/4/2012

PS Form 3526-R, August 2012

BUSINESS NEWS

PLANT WATCH

Novasep to build world's largest chromatography plant for APIs

October 10, 2012 — Novasep (Pompey, France; www.novasep.com) has announced an investment of €30 million to build what will be the world's largest chromatography plant for the production of commercial active-pharmaceutical ingredients (APIs). The plant will be built on Novasep's existing Mourenx site in France and will be operational and validated within 18 mo. The new plant, designed by a Novasep in-house engineering team, will include Varicol continuous-chromatography technology systems with 1,200-mm-dia. columns operated at up to 70 bars, said to be the largest ever built in the pharmaceutical industry.

Uhde to engineer one of the world's largest liquid fertilizer plants

October 12, 2012 — OCI Construction Group has selected ThyssenKrupp Uhde GmbH (Uhde; Dortmund, Germany; www.uhde.eu) for an engineering and procurement contract for the construction of one of the world's largest single-train liquid fertilizer plants to be built in the U.S. The plant with a daily production capacity of 4,300 metric tons (m.t.), will be built near Wever, Iowa. Orascom Construction Industries (OCI), is building the entire complex for its subsidiary, Iowa Fertilizer Company (IFCo). Commissioning is scheduled for 2015. This is said to be the first new sizeable fertilizer complex to be built in the U.S. in almost 25 years.

BASF and CSM establish 50-50 JV for bio-based succinic acid

October 5, 2012 — BASF SE (Ludwigshafen, Germany; www.basf.com) and Purac (Diemen, the Netherlands), a subsidiary of CSM (www.csmglobal.com), are establishing a joint venture (JV) for the production and sale of bio-based succinic acid. The company, to be named Succinity GmbH, will be headquartered in Düsseldorf, Germany, and will be operational in 2013. The establishment of Succinity GmbH is subject to filing with the relevant competition authorities. BASF and CSM are currently modifying an existing fermentation facility at Purac's Montmélo site near Barcelona, Spain, for the production of succinic acid. This plant, which will commence operations in late 2013 with a capacity of 10,000 m.t./yr of succinic acid, will put the new JV company in a leading position in the global marketplace. This is complemented by plans for a second large-scale facility with a capacity of 50,000 m.t./yr of succinic acid to enable the company to respond to the expected increase in demand. The final investment decision for this facility will be made following a successful market introduction.

Braskem Idesa awards large EPC contract for the Ethylene XXI project

October 4, 2012 — Braskem Idesa S.A.P.I. (a JV between Braskem SA of Brazil and Grupo Idesa of Mexico) has awarded a contract worth more than $2.7 billion (around €2.1 billion) for the engineering, procurement and construction (EPC) of a petrochemical complex to a JV formed by Odebrecht (40%), Technip (40%) and ICA Fluor (20%). The petrochemical complex to be built in the Coatzacoalcos/Nanchital region, in the Mexican state of Veracruz, will include a 1-million ton/yr, ethane-based ethylene cracker using Technip proprietary technology; two high-density polyethylene (PE) plants using Ineos Innovene technology; and a low-density PE plant using Basel Lupotech technology. The plant is expected to start up in June 2015.

Evonik plans to increase production capacity for 1-butene ...

October 1, 2012 — Evonik Industries AG (Essen, Germany; www.evonik.com) plans to increase the production capacity for 1-butene at its Marl, Germany site by 75,000 m.t./yr. Startup is scheduled for 2015.

...and plans the first MMA production plant using the Aveneer process

September 27, 2012 — Evonik Industries AG is starting basic planning for a new methyl methacrylate (MMA) production plant using the Aveneer process at its Mobile, Ala. site. The capital expenditure involved will be in the three-digit million-euro range. The plant, with a production capacity of 120,000 m.t., is expected to come onstream in the middle of 2015. The overall project is awaiting the approval of the relevant bodies. For more on the Aveneer process, see *Chem. Eng.*, November 2010, p. 16 (www.che.com/chementator/6105.html).

Demand for new technology drives multi-million AkzoNobel expansion

September 27, 2012 — AkzoNobel (Amsterdam, the Netherlands; www.akzonobel.com) is to boost capacity at one of its U.S. sites in order to meet increasing demand from the semi-conductor industry, particularly for the production of light emitting diodes (LEDs). The investment — at the company's Battleground facility in Texas — involves extending the tri-methyl-aluminum (TMAL) unit and building a new tri-methyl-gallium (TMG) plant. The expanded TMAL unit is expected to be completed in the 3rd Q of 2013, while the new TMG plant will be ready in August 2014. Financial details were not disclosed.

Wacker builds new dispersions plant in South Korea

September 24, 2012 — Wacker Chemie AG (Munich, Germany; www.wacker.com) is expanding its production capacity in South Korea for vinyl acetate-ethylene copolymer (VAE) dispersions. The company is constructing a new plant with a capacity of 40,000 m.t./yr at its site in Ulsan. This measure will almost double Ulsan's VAE dispersion capacity, making the enlarged production complex one of the biggest of its kind in South Korea. Wacker has budgeted around €10 million for the expansion project. The plant is expected to start up in January 2013.

Huber plans to increase silica capacity in Tennessee

September 21, 2012 — Huber Engineered Materials (Atlanta, Ga.; www.hubermaterials.com), a division of J.M. Huber Corp., has announced that it is increasing capacity at its precipitated silica plant in Etowah, Tenn. The expansion will add 14,000 m.t./yr at Etowah and is set for completion in the 3rd Q of 2013.

MERGERS AND ACQUISITIONS

Zachry Holdings acquires JV Industrial Companies

October 2, 2012 — Zachry Holdings, Inc. (San Antonio, Tex.; www.zhi.com) has completed the acquisition of JV Industrial Companies (JVIC), a Houston-based company serving clients primarily in the refining and petrochemicals sector. The combination of these businesses will result in one of the largest organizations dedicated to serving U.S.-based energy and industrial clients. Zachry will provide a wide range of services including engineering, construction, maintenance, turnarounds and fabrication, as well as a number of highly specialized services. ■

Dorothy Lozowski

FOR ADDITIONAL NEWS AS IT DEVELOPS, PLEASE VISIT WWW.CHE.COM

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FOR MORE ECONOMIC INDICATORS, SEE NEXT PAGE

Economic Indicators

2010 2011 2012

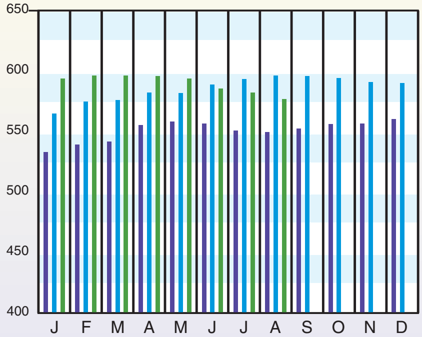
DOWNLOAD THE *CEPCI* TWO WEEKS SOONER AT *WWW.CHE.COM/PCI*

CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957-59 = 100)	Aug.'12 Prelim.	July '12 Final	Aug.'11 Final
***CE* Index**	576.7	582.2	596.1
Equipment	700.1	708.5	727.5
Heat exchangers & tanks	641.6	652.0	691.9
Process machinery	663.3	664.7	674.5
Pipe, valves & fittings	899.2	911.3	909.6
Process instruments	420.1	424.3	441.9
Pumps & compressors	929.0	928.9	909.9
Electrical equipment	511.3	509.7	512.6
Structural supports & misc	741.2	757.8	775.7
Construction labor	323.7	324.1	330.7
Buildings	524.5	525.6	521.1
Engineering & supervision	328.6	328.0	331.9

Annual Index:

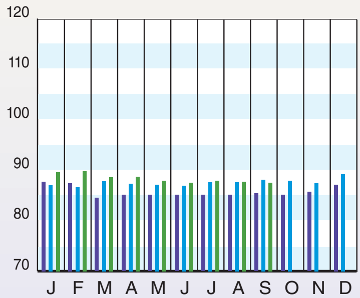
2004 = 444.2
2005 = 468.2
2006 = 499.6
2007 = 525.4
2008 = 575.4
2009 = 521.9
2010 = 550.8
2011 = 585.7



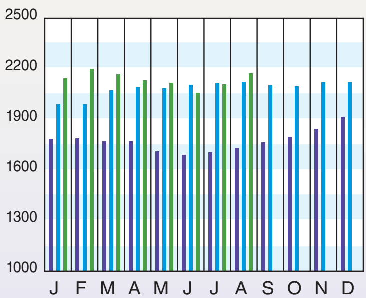
CURRENT BUSINESS INDICATORS

	LATEST		PREVIOUS				YEAR AGO	
CPI output index (2007 = 100)	Sep.'12	= 87.5	Aug.'12	= 87.7	Jul.'12	= 87.9	Sep.'11	= 88.1
CPI value of output, $ billions	Aug.'12	= 2,172.7	Jul.'12	= 2,108.8	Jun.'12	= 2,059.0	Aug.'11	= 2,124.7
CPI operating rate, %	Sep.'12	= 75.4	Aug.'12	= 75.6	Jul.'12	= 75.7	Sep.'11	= 76.1
Producer prices, industrial chemicals (1982 = 100)	Sep.'12	= 300.1	Aug.'12	= 292.9	Jul.'12	= 295.4	Sep.'11	= 336.0
Industrial Production in Manufacturing (2007=100)	Sep.'12	= 94.0	Aug.'12	= 93.8	Jul.'12	= 94.7	Sep.'11	= 91.1
Hourly earnings index, chemical & allied products (1992 = 100)	Sep.'12	= 158.2	Aug.'12	= 157.6	Jul.'12	= 159.0	Sep.'11	= 156.9
Productivity index, chemicals & allied products (1992 = 100)	Sep.'12	= 102.5	Aug.'12	= 102.9	Jul.'12	= 103.3	Sep.'11	= 107.2

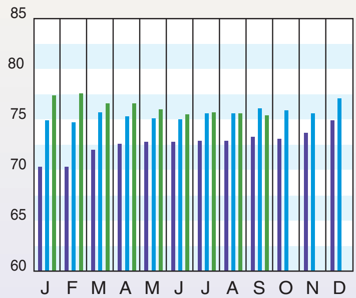
CPI OUTPUT INDEX (2007 = 100)



CPI OUTPUT VALUE ($ BILLIONS)



CPI OPERATING RATE (%)



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

CURRENT TRENDS

Capital equipment prices, as reflected in the *CE* Plant Cost Index (CEPCI; top), dropped 3.26% from July to August (the most recent data). Meanwhile, the Current Business Indicators from IHS Global Insight (middle), show less than a 0.3% decrease in the operating rate and output index, from August to September. At the same time there was a 3.03% increase in the value of output over the same time period, and a 2.46% average increase in the producer prices, industrial chemicals. Year over year, the trends in these numbers are a 0.68% decrease in the output index, a 2.26% increase in the value of output, a 0.92% decrease in the operating rate and a 10.7% decrease in the producer prices, industrial chemicals.

According to the American Chemistry Council's (ACC; Washington, D.C.; www.americanchemistry.com) latest weekly economic report at *CE* press time, The Organization for Economic Co-operation and Development (OECD) composite leading indicator (CLI) for August shows that most major world economies will continue to see weakening growth in coming quarters (also see p. 16)

For more on capital cost trends and historical CEPCI data, visit: www.che.com/pci ■