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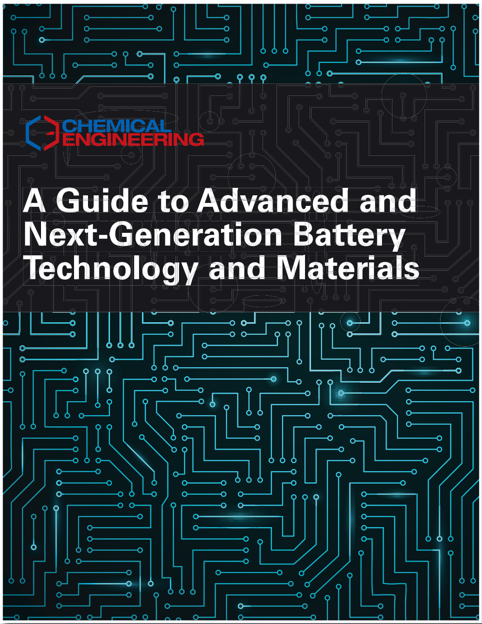
A Guide to Advanced and Next-Generation Battery Technology and Materials

This comprehensive guidebook provides descriptions of the major battery technologies and materials in the advanced and next-generation battery markets, as well as information on many of the companies operating in the advanced and next-generation battery industries.



Included in this guidebook is a table that represents a list of selected technology-development companies in the advanced battery space, along with their areas of focus, contact information and technology status. It lists both established companies and startup companies that have made technological strides in recent years toward commercially viable battery technologies.

- Major application areas for advanced and next-generation batteries
- Key parameters for advanced and next-generation batteries
- A sampling of academic and national laboratory research groups and lead investigators that are focused on technology for advanced batteries

Details Include:

- Driving forces
- Battery materials
- Supply-chain logistics
- Advanced batteries
- Li-ion variants
- Next-generation batteries
- Developments by application area
- Grid-energy storage
- Lithium-ion technology
- Advanced lead-acid batteries
- Wearable batteries
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Editor's Page

Focusing on water

Water is both a life-giving source and a potentially devastating force. Citing this range of water's power during the opening session of Weftec (New Orleans; September 24–28; www.weftec.org), New Orleans Mayor Mitch Landrieu described how the city has triumphed over the devastation that occurred eleven years ago when Hurricane Katrina hit. People now have a great appreciation for water, he said, where it may have at one time been taken for granted.

We are often reminded of the power of water — both too much and too little of it — such as with the recent force of Hurricane Matthew, and the droughts experienced in numerous places around the world. At Weftec's opening session, the many roles that water plays in our daily lives were depicted in a short video, which summed up water's importance with the potent message "without clean water, life stops."

For those of us who live in parts of the world where we haven't had to think much about our water supply, recent news like the water quality issues in Flint, Mich., have made us realize that having clean, fresh water is something that we cannot take for granted, and have to work to achieve.

A quantified approach to conservation

Water scarcity is a worldwide issue. In his keynote address at Weftec, Joe Whitworth said that with the world's growing population, water scarcity is a growing concern, and that "very few people see it coming." Whitworth is the president of the Freshwater Trust (Portland, Ore.; www.thefreshwatertrust.com), a not-for-profit organization that focuses on outcome-based conservation to protect freshwater resources.

Referencing his book, "Quantified: Redefining Conservation for the Next Economy," Whitworth gave examples of simple things that can be done, and quantified, to make a difference in water sustainability. One example involved a situation in Oregon where water effluents warmed the waterways they were being returned to, making them too hot for the salmon to exist. Cooling the water was accomplished by planting trees to shade the watershed, which was a much less expensive alternative than other solutions. Whitworth maintains that there is much that we can and should do to address water scarcity, and not just because it is the "right thing to do," but because it is the "smart thing to do." He says that the best investments are actually the most sustainable investments. To the Weftec audience, Whitworth emphasized that engineers can make a really big difference in worldwide water issues.

Advances in technology

The crowded aisles of Weftec's exhibit hall held examples of engineers and others working to improve wastewater treatment and related issues. As an example, results of a year-long demonstration of the Zeelung MABR* technology at the Metropolitan Water Reclamation District of Greater Chicago reportedly showed the potential for intensified nutrient removal as well as energy reduction. And scientists are working on innovative technologies, such as the plasma oxidation technology described on p. 7 in this issue.

The importance of clean, fresh water in our lives is something that many of us do not often focus on, until it is no longer available. It was inspiring to see the technologies presented at Weftec, and to meet some of the people who are indeed focusing their expertise on water-related issues. ■

Dorothy Lozowski, Editor in Chief

*For more on this technology from GE Power & Water, see "Turning wastewater treatment into resource recovery," *Chem. Eng.*, November 2015, p. 7

Your one-stop resource from drop in spray lances to tank washing nozzles

For over 60 years, BETE Fog Nozzle has been recognized as the leader in spray nozzle design and innovative solutions from custom spray lances and chemical injectors to tank cleaning nozzles. BETE's technological advancements have revolutionized nozzles used for atomizing, evaporation, cooling, misting, and fogging. Our in-house capabilities include all aspects of design, fabrication, and performance testing.

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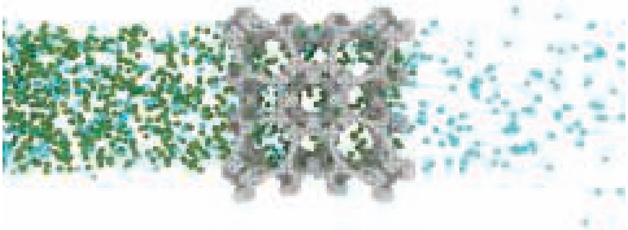
Commercial MOFs on the horizon

A partnership between materials company NuMat Technologies (Skokie, Ill.; www.numat-tech.com) and The Linde Group (Munich, Germany; www.the-linde-group.com) is set to bring metal-organic-framework (MOF) materials into the mainstream industrial-gas sector. Touted for their extremely high surface area and adsorption capacity, MOFs also have the ability to "tune" their properties based on the interactions between the metal component and the organic ligand, a major advantage. "These materials are essentially programmable in ways in which zeolites or carbons are not," says Ben Hernandez, NuMat chief executive officer. Using high-throughput supercomputing, a proprietary algorithm and experimental characterization, NuMat will sift through a library of millions of potential metal-ligand combinations to tailor MOFs with desirable characteristics for Linde's gas separation and storage applications (gas separation using an MOF is illustrated in the diagram).


NuMat Technologies

Precisely tuned pore size, for instance, is extremely important in kinetic-based separations, explains Hernandez. In the future, these MOFs may be deployed into Linde's existing and new installations. According to Hernandez, "This is one of the first times we're seeing a major company make a bold move in the context of integrating MOFs into existing system technologies. We look at this as a sign of things to come."

In gas-separation units, highly selective MOFs can significantly improve process recovery rates, reducing the number of operating cycles, as well as the compressor power expended for the separation process. For storage applications, MOFs are especially suited for absorbing highly toxic gases and storing them at low pressures without mechanical compression. The MOF can also act as a stabilizing scaffold for unstable products and protect against dangerous leaks. MOFs are prime for widespread industrial deployment, since they can be handled similarly to existing adsorbents, using off-the-shelf equipment. Furthermore, the solvothermal synthesis process used for MOF production is easily scalable, says Hernandez.

Plasma oxidation disinfects water without the addition of chemicals

A new technology that uses plasma to kill bacteria and simultaneously oxidize organic material in water systems offers a non-chemical alternative to water treatment in several industry sectors, such as food and beverage, power generation, oil and gas and others.

Symbios Technologies Inc. (Fort Collins, Colo.; www.symbiosplasma.com) has demonstrated its TPR4000 Tubular Plasma Reactor, which generates plasma using low-voltage, direct-current electricity applied across an array of plasma nozzles mounted on a rapidly (1,000 rpm) rotating cylindrical core. The plasma nozzles are equipped with porous frits that allow air to be introduced into the contaminated water, which flows into the reactor from the top and is mixed vigorously by the rotation. The air-supported plasma generates a variety of high-energy electrons and hydroxyl radical species that kill microbes and oxidize organic material in the water. The oxidation products are purged from the reactor as trace CO_2 and the decontaminated water exits the bottom of the reactor.

Current disinfection and wastewater-oxidation approaches rely on added chemicals, which have cost and safety issues, explains Symbios CEO Justin Bzdek. "The dynamic design of the patented Symbios plasma system allows the TPR4000 to be tuned for a variety of applications while delivering lower-cost, higher-performance oxidation and disinfection for water contaminants that are difficult to treat by other methods," he adds.

The Symbios technology can be scaled up by increasing reactor tube length and diameter, as well as by using multiple reactors in parallel. The company is seeking to add partners and investors as it takes the technology to the commercial stage.

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

Edited by:
Gerald Ondrey

COTTON DYES

Cotton Inc. (Cary, N.C.; www.cottoninc.com) and Archroma (Reinach, Switzerland) have collaborated to present what they believe is the first ever dye derived from cotton-plant residues. EarthColors is Archroma's method of creating dyes in warm, ternary shades from natural waste from the agricultural or herbal industry. The patented technology addresses two key concerns of the textile industry: sustainability and traceability. These sulfur-based dyes are designed for use on cellulosic fibers, such as cotton. Up to now, most dyes in the textile industry have been synthetic, derived from petrochemicals.

The global volume of cotton harvesting and ginning by-products — which includes burs, stems, immature bolls, lint, sticks, and leaves — can be as much as 3 million ton/yr, according to Archroma. One 480-lb bale of cotton, for example, can produce 150–200 lb of usable byproducts.

RENEWABLE JET FUEL

Last month, Gevo, Inc. (Englewood, Colo.; www.gevo.com) said it has completed production of the world's first cellulosic renewable jet fuel that is specified for commercial flights. The company adapted its patented technologies to convert cellulosic sugars derived from wood waste into renewable isobutanol, which was then further converted into Gevo's Alcohol-to-Jet (ATJ) fuel. This ATJ meets the ASTM D7566 specification allowing it to be used for commercial flights. Gevo produced over 1,000 gal of the cellulosic ATJ, and Alaska Airlines is expected to fly the first commercial flight using this cellulosic jet fuel in the next few months.

The cellulosic ATJ was

(Continues on p. 8)

produced in conjunction with the Northwest Advanced Renewables Alliance (NARA; Pullman, Wash.; https://nararenewables.org), which supplied the sugars that were derived from forest residuals in the Pacific Northwest. Gevo produced the cellulosic renewable isobutanol at its demonstration facility in St. Joseph, Mo., that it jointly operates with ICM Inc (Colwich, Kan.; www.icminc.com). The cellulosic renewable isobutanol was then transported to Gevo's biorefinery facility in Silsbee, Tex., which Gevo operates with South Hampton Resources, where the cellulosic renewable isobutanol was converted into ATJ.

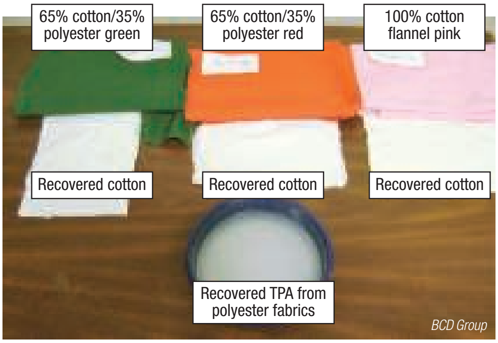
IMPROVING 3-D PRINTING

The presence of too much oxygen or humidity can pose a challenge to additive manufacturers because it can negatively impact the quality and performance of the item being printed. To ease this problem, Linde Gases (Pullach, Germany), a division of The Linde Group (Munich, Germany; www.linde.com) recently launched ADDvance O_2 precision, which the company says is a first-of-its-kind measuring and analysis unit that will enable metal-additive manufacturers to analyze and control more precisely the level of O_2 and humidity within the printer chamber. The new technology, developed in response to a need identified by aerospace company Airbus Group Innovations, can detect O_2 levels up to 10 parts per million (ppm) within the 3-D printer chamber, and then modify the gas atmosphere by adjusting the level of argon or nitrogen.

The launch of ADDvance O_2 precision comes on the back of Linde's recent opening of a dedicated industrial gases laboratory for additive manufacturing in Unterschleissheim, near Munich, Germany. The focus of the laboratory is to research the effect of different atmospheric gases and gas mixtures on the different metal powders used in additive manufactur-

(Continues on p. 11)

Recycling textiles into reusable cotton, polyesters and silver



Millions of tons of cotton-polyester-blend material that would normally be discarded in landfills could be recycled using a newly patented method for removing dyes from textiles, separating cotton from fabric blends, and depolymerizing polyesters.

The process, developed and demonstrated by BCD Group Inc. (Cincinnati, Ohio; www.bcdinternational.com), represents a departure from current fabric-recycling approaches, which often require high-temperatures, lengthy processing times and costly solvents. BCD's process occurs at 90–120°C in 10–20 min. and employs low-cost, reusable reagents in a way that retains the strength of the cotton fibers (photo). The easy-to-operate process also uses nontoxic chemicals that can be reused. Conventional depolymerization methods cannot be used for separating cotton-polyester blends because the high temperatures and long process times destroy cotton fibers.

In the BCD process, fabric blends of cotton and polyethylene terephthalate (PET) are shredded, then treated in a common stirred-tank reactor, with base and a proprietary phase-transfer catalyst (PTC). The PTC cleaves the bonds of dyes, polyesters and other chemicals bonded to cotton. The solid cotton fiber is removed from the reactor after processing for 10–20 min. before final depolymerization of PET. A small piece of polyester, used as indicator, confirms that the PET polyester has been removed from the cotton and converted to PET oligomers, along with monomers and ethylene glycol. Further processing completes the conversion of oligomers to terephthalate. After treatment, disodium terephthalate is treated with stoichiometric amounts of acid to produce terephthalic acid (TPA).

The TPA is recovered by filtration, washed and dried for reuse. The process has been demonstrated in a 57-L stainless-steel, stirred reactor, and a 25-gal autoclave, says Charles Rogers, a process engineer with BCD.

The process can be applied in recycling applications beyond textiles. "The nucleophilic reactions catalyzed by the PTC can be controlled," Rogers explains. With small changes in reagent composition, the dyes released from textiles can be retained rather than destroyed. BCD's process can also effectively recover monomers from composites and other polymers, and can recover silver metal from polymeric X-ray films. The company is looking for partners to help commercialize the technology.

This alkylation process uses an ionic liquid catalyst

A new alkylation technology that uses ionic liquids as a catalyst has been licensed by Honeywell UOP (Des Plaines, Ill.; www.uop.com), and will be marketed under the tradename Isoalkyl. The technology — developed by Chevron U.S.A. Inc., a subsidiary of Chevron Corp. (San Ramon, Calif.; www.chevron.com) — uses a non-aqueous liquid salt, at temperatures under 100°C, to convert a typical stream from a fluid catalytic cracker (FCC) unit into high-octane blending components for gasoline. Currently, most alkylation processes are based on hydrofluoric or sulfuric acid; more than half of the world's 700 petroleum refineries have alkylation units that use HF or H_2SO_4, according to UOP.

Ionic liquids have strong acid properties, enabling them to perform acid catalysis without the volatility of conventional acids, thus simplifying the handling procedures (see *Chem. Eng.*, October 2015, pp. 18–24). These liquid salts upgrade low-value C4 paraffins (butanes) and other olefins into a high-value blend component that helps to offset the combinations of gasoline-pool vapor pressure, sulfur, octane, aromatic and olefin content limitations, says UOP. Catalyst consumption with Isoalkyl is 400 times lower than H_2SO_4, and generates no heavy oil byproduct, according to UOP.

Chevron proved the new technology in a small demonstration unit at its Salt Lake City, Utah refinery, where it has operated for five years. The company plans to convert its HF alkylation unit in Salt Lake City to Isoalkyl technology. Construction is expected to start in 2017, pending permit approvals, and the unit will become fully operational in 2020.

Tin-based catalyst for photodecomposition

Daylight-driven photocatalysts have attracted much attention in the context of "green" technology for reducing pollutants. Although a number of active materials have been reported and their applications are rapidly increasing, many are discovered after enormous experimental efforts. Now, Isao Tanaka and colleagues at Kyoto University (Kyoto; www.kyoto-u.ac.jp), in collaboration with the Tokyo Institute of Technology (TiTech) and the Nagoya Institute of Technology (NiTech), have discovered a new photocatalyst system by using a highly efficient screening system based on theoretical calculations. The "discovered" catalyst — Sn(II)-based oxides, β-$SnMoO_4$ — was subsequently synthesized and shown to have the predicted photocatalytic activity. This catalyst was found after a "rational search" of 3,483 known and hypothetical compounds with various compositions and structures over the whole range of pseudo-binary systems, SnO-$MO_{q/2}$, where M = Ti, Zr and Hf (with q = 4); M = V, Nb and Ta (with q = 5); and M = Cr, Mo and W (with q = 6). Screening was performed using thermodynamic stability, band gap, and band-edge positions by density-functional-theory calculations, which identified β-$SnMoO_4$ as a potential target. Then, a low-temperature route was used to successfully synthesize the novel crystal, which was confirmed by X-ray powder diffraction and Mössbauer spectroscopy.

The β-$SnMoO_4$ catalyst has been shown to be active for the photocatalytic decomposition of a methylene blue solution under daylight irradiation, and its activity is comparable to a known photocatalyst, β-$SnWO_4$.

Making bio-oils via solvent liquefaction

At a pilot plant near Ames, Iowa, a team of researchers from Iowa State University (Ames; www.iastate.edu) and Chevron Corp. (San Ramon, Calif.; www.chevron.com) has validated the production of bio-oil via a new process technology called solvent liquefaction. Developed by Chevron, solvent liquefaction involves a proprietary solvent that is mixed with solid biomass, such as woodchips. At moderate temperatures and pressures, the mixture is processed into a slurry that is extruded into a heated reactor. The reactor operates in two distinct segments: an upper section where gases and vapors are handled, and a lower section for liquids and small amounts of solids. An array of filters and separation units serve to recover bio-oil and biochar, as well as the solvent, which is recycled back into the process. According to the team, the resulting bio-oil is low in oxygen, making it more stable than other bio-oils. The pilot plant processes about one pound of biomass each hour, and typically runs for 15–18-h shifts.

The project is supported by a four-year, $35-million grant from the U.S. Dept. of Energy's (DOE; Washington, D.C.) Biomass Research and Development Initiative. The collaboration began in 2013 when Chevron moved its $1.4-million Small Continuous Liquefaction Unit from Houston to the research farm near Ames.

A microwave-assisted flow reactor for organic synthesis

Saida FDS Inc. (Shizuoka, http://saidagroup.jp/fds_en/) has commercialized a flow reactor that uses microwaves to produce fine chemicals and pharmaceutical intermediates at high temperatures and pressures. The system has been shown to boost productivity by a factor of 3–6 compared to existing metal tubular flow-reactor systems that are externally heated. The reactor was developed with support from the New Energy and Industrial Technology Development Organization (NEDO), in collaboration with the National Institute of Advanced Industrial Science and Technology (AIST), University of Shizuoka, Shizuoka University and Gifu Pharmaceutical University. In September, Saida FDS began shipping the first commercial units in Japan, with microwave powers of 50, 100 and 200 W, and has obtained certification for supplying 100-W units overseas within the next year.

The reactor is a bench-scale system that is rated for operation at temperatures up to 230°C and pressures to 2.5 MPa, and includes possibilities for realtime monitoring of continuous reactions.

The reactor's high productivity has been demonstrated for the Fisher indol synthesis of the pharmaceutical intermediate 2,3,4,9-tetrahydro-1H-carbazol from cyclohexane and phenylhydrazine. A yield of 3 kg/d was achieved with a microwave power of 140 W, a flowrate of 15 mL/min and a pressure of 2.6 MPa. The high productivity is due, in part, to the very high-speed optimization of the synthesis conditions using flow monitoring and mathematical statistics for quickly changing the heating conditions to ensure proper temperature control. As a result, separation and purification of the product is simplified, says the company.

The researchers believe the system can also be used for multi-phase gas-liquid reactions using ultra-fine bubbles, enabling the low-cost production of complex and potentially dangerous chemicals.

This desalination process uses much less energy than RO

An adsorption desalination and cooling (ADC) plant has been implemented at Solar Village near the Saudi Arabian capital of Riyadh, by King Abdulaziz City of Science and Technology (KACST; www.kacst.edu.sa). The project to build the plant resulted from a collaboration of King Abdullah University of Science and Technology (KAUST; Thuwal, Saudi Arabia; www.kaust.edu.sa), TAQNIA (Saudi Investment Co., Riyadh; www.taqnia.com) and Medad Technologies Pte. Ltd. at the National University of Singapore (www.medad-tech.com). General contractor Medad joined forces with KACST and Polish company NET to execute all engineering, manufacturing and installation works.

The plant is said to be the world's largest adsorption-chiller installation, with a cooling capacity of up to 1 MW and production of up to 100 m^3/d of desalinated water. The plant's electricity consumption is below 1.2 kWh/m^3 (about 75% lower than reverse osmosis). Power is required only for water pumps and valves. The plant's operating costs are below \$0.40/m^3 of water.

The adsorption system consists of a pair of tube-fin heat exchangers, each packed with silica gel. The exchangers alternate between adsorption and desorption. In the adsorption mode, water vapor from the evaporator is adsorbed on the silica gel, which lowers the pressure in the evaporator to enhance the speed of evaporation while lowering the temperature required for boiling. The loaded adsorbent is then indirectly heated with warm (65–85°C) water, which is generated from solar energy or low-grade heat recovered from industrial sources. Water ejected from the silica gel is collected by a condenser.

The plant operates with seawater containing up to 280,000 parts per million (ppm) total dissolved solids (TDS), and the silica beds do not require any cleaning. The produced water has a TDS of 0–2 ppm with a conductivity of less than 5 µS (micro-Siemens).

The search for salt-tolerant microbes for improved bioleaching

In response to water scarcity and declining grades of ore, the mineral processing industry has been investigating ways to improve processes, such as bioleaching to deal with increased impurity concentrations in process streams.

Advantages of bioleaching for low-grade ores, such as chalcopyrite, are well known. However, the efficiency of bioleaching is dramatically reduced in moderately brackish or saline water, because anions (for instance Cl^- and SO_4^{-2}) can acidify microbial cells responsible for bioleaching, resulting in loss of activity or even cell death, and decreasing the overall yields of the process.

Researchers from the Environmental and Industrial Biotechnology Team at CSIRO (Perth, Western Australia; www.csiro.au) and the University of Western Australia (Perth; www.uwa.edu.au) are studying how increasing sulfate concentrations can affect the efficiency of chalcopyrite bioleaching with the intent to improve process yields in saline conditions. Using chalcopyrite concentrate sourced from Mount Isa Mines in Queensland, the team studied the efficiency of chalcopyrite bioleaching at mesophilic (30°C), moderately thermophilic (45°C), and thermophilic (60°C) temperatures in the presence of elevated sulfate concentrations.

The microbes were able to bioleach copper from chalcopyrite concentrate in the presence of high sulfate background (up to 100 g/L for the mesophilic culture). Copper extraction was greatest at 60°C (48%) followed by 45°C (22 %) and 30°C (16 %), and overall yields after 31 days were similar to previous results for bioleaching in non-sulfate backgrounds.

The team says that bioprospecting, adaptation and identification of salt-tolerant, acidophilic bioleaching cultures has the potential to reduce the requirement for fresh, potable water, while also improving the bioleaching efficiency of low-grade minerals with anionic impurities. Further research characterizing the salt-tolerant microbes responsible for bioleaching in saline conditions is currently underway.

Making ammonia at milder conditions

Ammonia is a crucial chemical feedstock for fertilizer production, as well as a potential energy carrier. However, the current, century-old method of synthesizing ammonia, the Haber–Bosch process, consumes a great deal of energy, operating at high pressures (several hundred atmospheres) and temperatures (400–600°C). To reduce energy consumption, a process and a substance that can catalyze ammonia synthesis under mild conditions (350–400°C and 10–100 atm) are needed. Now, associate professor Katsutoshi Nagaoka and colleagues at the Faculty of Engineering, Oita University (Japan; www.oita-u.ac.jp) have developed a ruthenium nano-layer supported on praseodymium oxide (Ru/Pr_2O_3), which is said to have the world's highest catalytic activity for NH_3 synthesis under relatively mild conditions.

The researchers showed that Ru/Pr_2O_3 — without any dopant — catalyzes NH_3 synthesis with a production velocity of about 15,000 µmol/g·h, which is almost 1.8 times that of other reported highly active catalysts, such as Ru/CO_2 and Ry/MgO. A space velocity of 18 L/g·h was observed at a reaction pressure of 9 atm and temperature of 390°C.

The new catalyst system has the following two features: (1) Ru is supported on the Pr_2O_3 catalyst as low-crystalline nano-layers (0.3–5-nm thick) on the surface of Pr_2O_3; and (2) the Ru/Pr_2O_3 catalyst system was strongly basic. These unique structural and electronic characteristics are thought to synergistically accelerate the rate-determining step of NH_3 synthesis — cleavage of the N_2 triple bond.

Ethanol from CO_2

Scientists at the U.S. DOE's Oak Ridge National Laboratory (ORNL; Tenn.; www.ornl.gov) have developed an electrochemical process that directly produces ethanol from CO_2. The researchers used a catalyst consisting of copper nanoparticles embedded in carbon spikes, and applied voltage to trigger a reaction that is essentially the reverse of combustion. The catalyst contains multiple reaction sites, and converts an aqueous solution of CO_2 directly into ethanol with a yield of 63%.

ing in order to optimize the various layering processes. Reproducibility is one of the most important parameters for industries requiring strict consistency in end products, such as the aerospace and automotive industries.

RECOVERING LIGNIN

VTT Technical Research Center of Finland Ltd. (VTT; Espoo; www.vtt.fi) has developed eutectic solvents that can efficiently and cost-effectively separate lignin from sawdust. The advantage of the process is that the recovered lignin retains its natural chemical structure during processing. Conventional processes produce lignin in a form that is much less usable, so normally lignin is simply used for combustion in energy production, says VTT. The eutectic solvents are prepared by simply heating and stirring two components, and are said to be inexpensive compared to conventional ionic solvents. ❑

Solution mining technique improves potash yields

A new patent-pending solution-mining technique known as SMER (selective mining with enhanced recovery), developed by Innovare Technologies Ltd. (Carlyle, Sask.; www.innovaretechnologies.ca), can increase yields of potash (potassium chloride; KCl) and achieve lower operating and capital costs compared to traditional potash solution-mining methods.

Potash is a global commodity chemical used primarily as a fertilizer to improve crop yields. It can be found naturally as pure KCl, known as the mineral sylvite, but is most often found as a dual ore deposit with sodium chloride (NaCl) and is known as sylvinite. Potash is typically recovered by primary solution mining, where heated water is injected into a drilled mine cavern to dissolve both KCl and NaCl. KCl is isolated from the returning brine solution with an evaporative crystallizer. Typically, recovered NaCl is stockpiled on the surface and can become an environmental legacy. In conjunction, caverns in which primary mining has been performed also undergo secondary mining with brine that contains a depleted level of KCl and a close-to-saturation concentration of NaCl. This secondary-mining technique is designed to leave NaCl behind, while extracting the desired KCl.

Innovare's SMER technique offers the selectivity advantages of secondary mining without the need for initial primary mining of KCl. SMER can achieve higher per-pass yields of KCl, while eliminating the equipment and energy required to process brine from primary mining in traditional potash harvesting, explains John McEwan, president of Innovare. Return brine in the SMER process is at 10°C, where the solubility limit of KCl is 8.8 wt. %, compared to a typical evaporative KCl crystallizer, which is limited to about 40°C (KCl solubility limit of 13.4 wt.%).

The defining characteristics of the process are its ability to use heating and cooling intelligently to cool KCl-containing brine while warming weak brine for reuse in the cavern. The final cooling step, following a series of cooling crystallizers, makes use of steam-generated chilled water for cooling the return brine. Steam required for chilled water, along with the steam required for processing, provides a useful energy sink for a steam turbine/generator to produce co-generated electrical power without the use of a condensing turbine. Enough power can be generated to meet the mine and plant requirements. This allows for a single energy source, such as natural gas, to meet all steam and power requirements. Innovare is looking to license the SMER technology. ■

Business News

Plant Watch

Covestro doubles polycarbonate resin production capacity in Shanghai

October 12, 2016 — Covestro AG (Leverkusen, Germany; www.covestro.com) is doubling production capacities for polycarbonate resin from 200,000 to 400,000 metric tons per year (m.t./yr) by inaugurating two new production lines at its site in Shanghai, China. The new production lines are the last cornerstone of a multi-year investment program for the Shanghai site worth over €3 billion.

Ube Industries to increase nylon manufacturing capacity in Spain

October 12, 2016 — Ube Industries, Ltd. (Ube; Tokyo, Japan; www.ube-ind.co.jp) will invest in additional nylon manufacturing capacity at its subsidiary, Ube Corporation Europe S.A.U., in Castellon, Spain. The expansion will add 40,000 m.t./yr, bringing the total capacity to 70,000 m.t./yr. The new capacity is expected to start operation in the beginning of February 2018. At the same location, Ube is also building a new compounding facility, which will start operation in August 2017.

Arkema to construct polyester- powder resin plant in India

October 11, 2016 — Arkema (Colombes, France; www.arkema.com) plans to construct a new polyester-powder resin manufacturing facility, said to be the first of its kind in India, at its existing resin site in Navi Mumbai, Maharashtra. The project, which represents an investment of approximately $15 million, is targeted for completion in 2018.

Axens to license tehnologies for major refinery upgrades in Indonesia

October 11, 2016 — Axens (Rueill-Malmaison, France; www.axens.net) signed several technology licensing agreements with PT Pertamina (Jakarta, Indonesia; www.pertamina.com) for expansion projects at petroleum refineries in Balikpapan and Cilacap, Indonesia. In Balikpapan, Axens will supply technologies for a fluidized catalytic cracker, sulfur removal, propylene recovery and a middle-distillate hydrotreater. The Cilacap project consists of a grassroots distillate-hydrotreater unit.

Amec Foster Wheeler awarded Singapore Refining Co. contract

October 5, 2016 — Amec Foster Wheeler (London, U.K.; www.amecfw.com) was awarded a contract by Singapore Refining Co. (SRC), a joint venture (JV) between Singapore Petroleum Co. and Chevron Corp., to upgrade SRC's crude and vacuum heater efficiency, including burner revamps, air preheaters and a common new chimney stack at its site at Jurong Island.

Praxair starts up hydrogen plant at Repsol refinery in Peru

October 4, 2016 — Praxair, Inc. (Danbury, Conn.; www.praxair.com) started up a hydrogen plant at Repsol's La Pampilla petroleum refinery in Callao, Peru. The new steam methane reformer (SMR) has a capacity of 12 million std ft^3/d. A new Praxair facility adjacent to the hydrogen plant will recover and purify carbon dioxide generated by the SMR for the production of food-grade liquid CO_2.

Evonik breaks ground in Austria for membrane-module production plant

September 30, 2016 — Evonik Industries AG (Essen, Germany; www.evonik.com) broke ground in Schörfling, Austria for an additional operations complex for producing gas-separation membrane modules. In addition to a new hollow-fiber spinning plant, the facility will include further spaces for research and development, application technology and a warehouse. The new plant, which will double the existing production capacity, is scheduled to open in late 2017.

Novamont opens commercial-scale facility for bio-based BDO

September 29, 2016 — Novamont S.p.A. (Novara, Italy; www.novamont.com) opened a commercial-scale facility in Bottrighe, Italy that will produce 30,000 m.t./yr of 1,4-butanediol (BDO) from renewable sources. The plant uses technology from Genomatica (San Diego, Calif.; www.genomatica.com) to convert sugars to BDO, and is expected to reach full production rates in 2017. Novamont invested approximately $110 million to build the plant.

Borealis announces feasibility study for new propane dehydrogenation plant

Borealis AG (Vienna, Austria; www.borealisgroup.com) will study the feasibility of a new propane dehydrogenation (PDH) plant to be located at the existing Borealis production site in Kallo, Belgium. The final investment decision is expected to be made in the third quarter of 2018, while the potential startup of the plant is scheduled for the second half of 2021. The new PDH plant would have a targeted production capacity of 740,000 m.t./yr.

Mergers & Acquisitions

Total sells specialty chemicals affiliate Atotech for $3.2 billion

October 11, 2016 — For the divestiture of its specialty chemicals affiliate, Atotech B.V., a global manufacturer of high-tech plating solutions, Total S.A. (Paris; www.total.com) has accepted an offer from The Carlyle Group (www.carlyle.com). In the framework of this transaction, Total will receive $3.2 billion.

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BASF and Avantium form JV for renewable FDCA and PEF

October 11, 2016 — BASF SE (Ludwigshafen, Germany; www.basf.com) and Avantium (Amsterdam, the Netherlands; www.avantium.com) formed a new JV, called Synvina, for the production and marketing of furandicarboxylic acid (FDCA) produced from renewable resources and polyethylenefuranoate (PEF) based on renewable FDCA. Synvina plans to build a 50,000-m.t./yr reference plant at BASF's Verbund site in Antwerp, Belgium.

Rockwell Automation acquires Maverick Technologies

October 3, 2016 — Rockwell Automation (Milwaukee, Wis.; www.rockwellautomation.com) acquired systems integrator Maverick Technologies (Columbia, Ill.) to expand domain knowledge and help deliver control and information solutions to customers in the chemical, food-and-beverage, and oil-and-gas industries. The acquisition strengthens Rockwell Automation's expertise in key process and batch applications.

Air Products' Versum Materials becomes independent company

October 3, 2016 — The former Electronic Materials business of Air Products (Lehigh Valley, Pa.; www.airproducts.com) is now a separate and independent public company: Versum Materials, Inc. Versum, a leading semiconductor industry supplier, will continue expanding its Tempe, Ariz. headquarters in the coming months and focus on meeting the needs of the semiconductor and other electronics-related industries.

Emerson to acquire corrosion monitoring specialist Permasense

October 3, 2016 — Emerson (St. Louis, Mo.; www.emerson.com) announced it has agreed to acquire U.K.-based Permasense Ltd., a leading provider of non-intrusive corrosion-monitoring technologies. Permasense monitoring systems use sensors, wireless data delivery and analytics to continuously monitor for metal loss from corrosion or erosion in pipes, pipelines or vessels.

Lanxess to acquire Chemtura for €2.4 billion

September 26, 2016 — Lanxess AG (Cologne, Germany; www.lanxess.com) plans to acquire Chemtura Corp. (Philadelphia, Pa., www.chemtura.com), one of the major global providers of flame-retardant and lubricant additives. The transaction, which has an enterprise value of approximately €2.4 billion, is expected to close around mid-2017. Chemtura is slated to join Lanxess' Advanced Industrial Intermediates business unit.

Solvay to divest OLED portfolio to Nissan Chemical Industries

September 21, 2016 — Solvay S.A. (Brussels, Belgium; www.solvay.com) has reached a final agreement with Nissan Chemical Industries Ltd. to divest most of its OLED (organic lighting-emitting diode) patent portfolio. The sale follows a strategic analysis showing that new display technologies are being delayed. As a consequence, Solvay has decided to stop its research activities in this area. ■

Mary Page Bailey

A Look Inside Advanced Materials Analysis

Testing and characterization techniques are rising to meet the demands of increasingly complex materials and applications

DSM

FIGURE 1. DSM's dedicated materials-testing facility will condition engineering plastics in order to evaluate their performance in a variety of processing and end-use applications

IN BRIEF

TESTING PRODUCT QUALITY

IMPROVED STATISTICAL ANALYSIS

A TOOLKIT FOR COMPOSITE INSPECTION

TERAHERTZ TECHNOLOGIES

Ensuring the integrity of materials is essential in the chemical process industries (CPI) for the continued maintenance of long-lifetime process equipment like vessels and pipelines, usually via nondestructive testing (NDT) techniques such as ultrasonic, eddy-current, radiographic or guided-wave testing. Many companies also must employ materials testing and characterization techniques for quality assurance of the products they are selling. Both facets of materials analysis — whether inspecting equipment used in processes or the products of the processes themselves — demand that companies stay up-to-date with the most modern methods for materials testing and characterization.

Sizable recent investments in dedicated materials-testing facilities by major companies underline the significance of these efforts. Furthermore, accelerated developments in applications for complex materials, such as composites and nanomaterials, have necessitated the adoption of more advanced testing and characterization methods.

Testing product quality

In September, Royal DSM (Heerlen, the Netherlands; www.dsm.com) announced a $5-million investment to open a dedicated research and technology center (Figure 1) for its DSM Engineering Plastics division in Troy, Mich. "The focus that DSM is placing on advanced testing methods comes from an eagerness to validate the performance of its products under application-relevant conditions," says Juliana Bernalostos-Boy, manager of application and product testing at DSM Engineering Plastics. According to William Senge, director, research and technology, Americas for DSM Engineering Plastics, by emphasizing application-specific experiments and close collaboration with customers, the site will "bridge the gap between intrinsic materials characterization and application testing." These tasks will include fluid aging of plastics, as well as simulations of key secondary operations the plastics may encounter at customers' sites, says Senge. In order to most accurately test engineering plastics for their behavior in end-use applications, the materials will be exposed to application-relevant conditions prior to testing via a variety of conditioning options, including ovens, environmental chambers and chemical-resistance setups. "The environmental chambers will allow us to condition parts and materials to 95% relative humidity at 95°C. This is an extremely aggressive conditioning that we see becoming more and more relevant in future applications," explains Bernalostos-Boy.

When testing nanomaterials and their end products, special conditions must be considered. A collaboration between Oxford

Instruments plc (Abingdon, U.K.; www.oxford-instruments.com), National Physical Laboratory (NPL; Teddington, U.K.; www.npl.co.uk) and the National Graphene Institute (NGI, Manchester, U.K.; www.graphene.manchester.ac.uk) is seeking to develop a turnkey commercial metrology system for graphene characterization and various other nanotechnology applications, such as high-end instrumentation. Such a system would not only decrease costs and complexity, but would establish the industry's first-ever set of primary resistance standards, allowing for extremely precise resistance calibrations and other measurements during the production of instrumentation devices and other electronics. By taking advantage of graphene's manifestation of the quantum Hall effect, a phenomenon used to determine electrical resistance using low temperatures and strong magnetic fields, the group will harness this behavior to accelerate the commercial adoption of graphene by enabling commercially applicable nanoscale materials characterization.

Improved statistical analysis

For obtaining useful information from materials characterization, the method of analyzing the results can be as important as the characterization method itself. A research team from North Carolina State University (NCSU; Raleigh; www.ncsu.edu), the National Institute of Standards and Technology (Gaithersburg, Md.; www.nist.gov) and Oak Ridge National Laboratory (Oak Ridge, Tenn.; www.ornl.gov) has found a new analysis method that yields even more useful characterization results from diffraction and spectroscopy data (Figure 2). "Currently, the dominant method of analyzing diffraction patterns involves modeling the material as a single unit cell. The parameters in this model are refined using a 'least squares' approach, which leads to single estimates of each structural parameter," says Jacob Jones, NCSU professor of materials science and engineering. However, explains Jones, since materials are naturally heterogeneous, this method results in an oversimplified representation of the actual material structure.

North Carolina State University

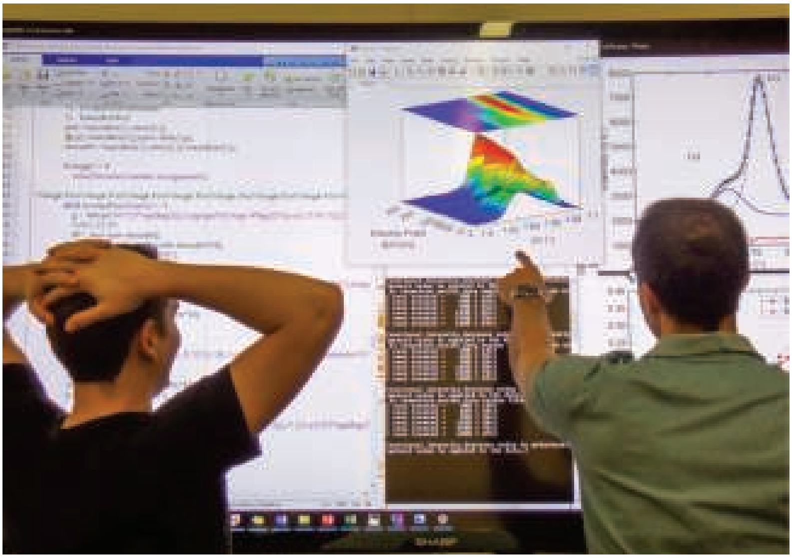


FIGURE 2. Analyzing materials-characterization data at the atomic level using probabilistic terms yields more useful results

The new characterization approach, based on Bayesian statistics, allows for materials' structural features to be described in terms of probability distributions, rather than a single value assumed for a model of a single unit cell. Table 1 illustrates how results from least squares and Bayesian statistical analysis could differ, in terms of a hypothetical measurement of a single bond distance. "Using probability distributions instead of single-valued solutions provides a better ability to predict or calculate how these materials will perform in applications, and a better way of qualifying manufactured materials," says Jones.

The team believes that the ability to assess materials' structure in probabilistic terms will prove to be extremely valuable for quality assurance and process monitoring for products such as metals, ceramics and powders. "A useful analogue would be to consider the manufacture of particles — a customer should want to know the size distribution of the supplied particles, not simply an average or most-likely size," describes Jones.

Although the Bayesian analysis approach is based on ubiquitous characterization techniques like diffraction and spectroscopy, making it powerful and applicable across various industries, Jones says that widespread adoption is not without challenges. "One immediate challenge to adoption is the development of software that can readily incorporate this method in evaluating diffraction and spectroscopy data. Codes can readily be written by a specialist, but we need to make them widely available to industry."

The method is particularly useful for materials whose structures are difficult to characterize using a single type of experiment and require consideration of multiple characterization methods, such as metal oxides. The Bayesian method allows users to integrate data sets from different experiments to obtain better certainty. The team also cites the method as being well-suited for analyzing composite materials consisting of dissimilar material structures.

A toolkit for composite inspection

There is no doubt that the nature of the material being tested can impact the effectiveness and application of certain testing techniques. Composite materials, due to their complex internal structures, possess many properties that make them suitable for heavy-duty applications in aerospace, renewable energy and many other industries. These applications demand reliable longterm performance, so ensuring materials' integrity is key.

Researchers at Sandia National Laboratories (Albuquerque, N.M.; www.sandia.gov) are investigating

TABLE 1. COMPARISON OF HYPOTHETICAL ANALYSIS RESULTS IN TERMS OF SINGLE BOND DISTANCE IN ANGSTROMS (Å)

Least squares approach	2.462 Å for the model of a single unit cell within a heterogeneous material
Bayesian approach	99% probability that all bond distances are between 2.4 and 2.5 Å

NDT methods for composites. "The techniques that we've focused on are currently being deployed in a laboratory setting. We use a range of handheld devices that can be taken into the field as well as scanning platforms that are designed to collect a tremendous amount of data very quickly," says David Moore of Sandia National Laboratories. Two techniques being investigated are infrared imaging, and ultrasonic scanning devices, such as hand-contact roller probes. Both methods can cover a wide range of sample sizes. Moore emphasizes that each testing method brings with it unique capabilities and limitations, and when used together will create a comprehensive toolbox for inspecting composites. "Each method tells a little portion of the story. Ultrasonics can measure material thickness; infrared technologies can measure surface temperatures, so both techniques coupled together give a better idea of what is happening with a material during its service life."

According to Moore, a composite's porosity is one of the primary parameters that must be known. Moore's research is focused on the group of composites known as prepregs, where the resin is "impregnated" within the carbon material.

Here, a sample is laid out in plies and stacked for the desired thickness. Air is rolled out of the ply stack before being placed in an autoclave for the curing cycle. Temperature is applied to the parts, and pressure and time are two additional parameters that can be varied. As temperature increases, the resin viscosity decreases until glass transition is reached. At this point, the void pressure is high. To eliminate void formations, the desired autoclave pressure must be applied at minimum viscosity. If pressure is applied prior to minimum viscosity, voids will be trapped inside the resin and porosity will be created within the component. "This means that the ply layers are not bonded cohesively and the porosity creates a stress initiation site for potential material failure," explains Moore. Porosity variances, as well as density changes, can be detected by measuring the acoustic wave as it travels through a sample. Air bubbles scatter sound, so the porosity can be evaluated by measuring the attenuation change through the material thickness.

Another important feature within composites is the alignment of the fibers, or tow. In many applications, misalignments can indicate causes for concern, so their presence and severity should be assessed. Also, the transition from thicker to thinner areas within a composite can create a large stress concentration. "These transitions are the most difficult areas to inspect," says Moore, because researchers must know the exact locations simply from looking at a drawing. Ultrasonic and infrared rapid scanning systems denote localized thickness on screen using *x-y* coordinates. "If the composite has been impacted during service, we would like to understand what any of these inspections can tell us about the remaining strength of a component," Moore says. "If you know the strength, then you can develop proactive maintenance schedules around the collected inspection data."

Terahertz technologies

An area of emerging technology in the NDT realm is terahertz (THz) devices — those that operate in the frequency range between radio and microwaves. Much work has been done in harnessing THz radiation for materials testing and characterization purposes because of its high chemical selectivity and ability to penetrate typically opaque or translucent materials, as well as take complex measurements within multi-layer structures. THz is especially useful with non-metallic materials, such as plastic, rubber, glass, ceramic and wood. "Compared to the conventional methods used for nondestructive material testing, such as radiography

Fraunhofer HHI

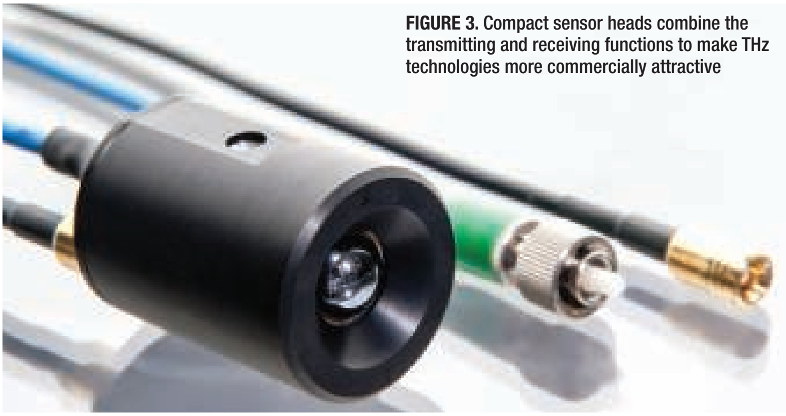


FIGURE 3. Compact sensor heads combine the transmitting and receiving functions to make THz technologies more commercially attractive

or ultrasound, terahertz technology enables non-contact inline measurements using small-footprint testing equipment. Especially in high-volume productions like polymer tubes, it is essential to have direct feedback to control the production process," explains Joachim Giesekus, head of the Terahertz Sensors and Systems Group at Fraunhofer Heinrich Hertz Institute HHI (Berlin, Germany; www.hhi.fraunhofer.de). Previously, THz technology was almost strictly limited to academic and research settings, but recent advances have made it more accessible for industrial use. "Until now, terahertz devices, in particular the sensor heads, have been expensive and bulky," Giesekus says. Earlier this year, at Hannover Messe, Fraunhofer HHI debuted a breakthrough in THz measuring devices — a system with compact sensor heads constructed from low-cost materials (Figure 3). In typical THz measuring systems, the sensor heads' receiver and transmitter are two distinct components that must be carefully mounted within a casing. This arrangement dictated that measurements be taken at a precise angle, making the system especially susceptible to changes in positioning due to vibration, for instance. Fraunhofer HHI's compact sensor heads feature an integrated chip — dubbed a "transceiver" — that can simultaneously transmit and receive.

While these prototype sensor heads have mainly been used for inline defect detection in the production of plastic pipes, Giesekus says they are also suitable for analyzing coatings on fiber composites and inspecting defects in polymer devices. Traditional NDT devices, such as those utilizing eddy-current methods, are well-suited for use with metallic substrates, but they fail with fiber composites, which have poor conductivity. Here, THz technologies can provide many benefits, although Giesekus emphasizes that the prototype sensor heads are still 1–2 years away from widespread adoption. "The development of semiconductor materials optimized for sending and receiving THz radiation is still challenging," he says. In addition to the sensor heads, Fraunhofer HHI is also working to develop next-generation THz spectrometers.

Another group touting the advantages of THz technologies for NDT is TeTechS (Ontario, Canada; www.tetechs.com), which has developed TeraGauge, an NDT device designed specifically for use in industrial environments, where dust, humidity and other interferences may be present. "Terahertz has long been viewed as elusive, and has only recently emerged as a real-world solution amongst major players like x-ray and infrared technologies," says TeTechS founder and chief executive officer Daryoosh Saeedkia, citing expense as a main factor that has limited THz's expansion beyond research applications. However, he describes several advantages of THz over traditional NDT methods. "Unlike x-rays, terahertz is non-ionizing, which ensures it is not harmful to the user. Furthermore, when compared with ultrasonic or infrared techniques, THz is less sensitive to sample position and environmental factors, such as vibration, temperature and humidity." TeraGauge employs a "time-of-flight" principle (Figure 4), which uses the speed of light in the material under test to extract parameters such as thickness or density. TeTechS has recently employed TeraGauge technology inside IMDvista Layer industrial measurement systems, aiding in the inspection of the thickness of multilayer plastic containers and thin-wall packaging. TeraGauge is also applicable for void detection and multilayer thickness inspection of hoses, tubes, paints and coatings. In addition to TeraGauge, the company is also developing handheld THz devices and a THz-powered fiber-coupled gage for rapid inline measurements.

As the CPI continue to demand more complex materials for increasingly challenging applications, materials testing, characterization and inspection will certainly be an essential factor for ensuring ongoing operational success. ■

Mary Page Bailey

TeTechS

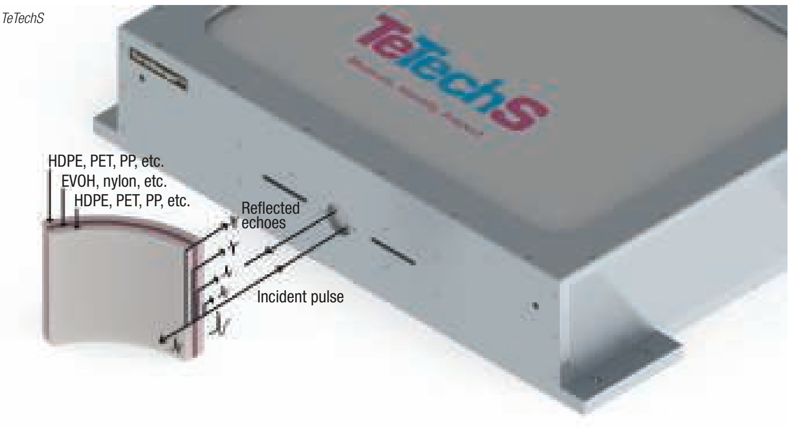


FIGURE 4. A time-of-flight approach allows THz-based inspection of multilayer plastic parts

The Changing Face of Maintenance

Connected enterprises and intelligent instrumentation promote predictive maintenance and improve reliability

Process reliability is one of the most important factors in achieving a profit for producers in the chemical process industries (CPI). However, maintenance departments in these facilities deal with many challenges, including disorganized data, limited budgets and loss of talent. The good news is that software that promotes connected enterprises and intelligent instrumentation, combined with increased mobility via smartphones and tablets, is changing the way maintenance crews handle their tasks and helping to increase reliability.

Emerson

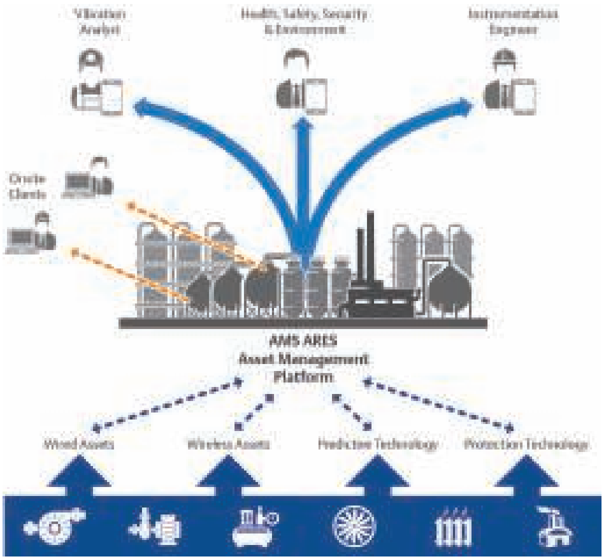


FIGURE 1. Emerson's ARES Asset Management Platform collects asset data from field-based wired and wireless sensors and delivers information on the most critical situations to the appropriate personnel, enabling users to make well-informed decisions regarding maintaining reliability and availability

IN BRIEF

DEALING WITH DATA

DOING MORE WITH LESS

INTELLIGENT INSTRUMENTATION

Dealing with data

While there are many obstacles to overcome in order to keep a CPI facility running, one of the biggest maintenance woes is disorganized data.

"Right now there's tons of available information, but not all of this is essential or relevant," says Mark Granger, Industry Solution Manager with Emerson (Round Rock, Tex.; www.emerson.com). "With so much information coming at them, maintenance managers and technicians often have a difficult time figuring out what information is essential to their jobs. How do you take raw signals from thousands of instruments and turn them into data and decide which of that information is actually important and relevant? How do you receive ten thousand alerts and narrow it down to the two or three most important pieces of information so you know what to react to today?"

In order to organize the data and send it to relevant personnel, says Granger, it is necessary to combine process information with condition-based equipment information obtained from pervasive, intelligent sensing. "Process data provide information that is relevant to how the assets are performing and machine-based condition information provides data relevant to the health of the equipment. Process performance is an indicator of equipment health and vice versa," he says. "If one is deteriorating, so will the other, because there's a direct correlation between equipment health and performance."

For this reason, data often need to be shared between multiple disciplines in the facility. "That's the main function of Emerson's Advanced Reliability Expert System (ARES) product," says Granger. Emerson's ARES Asset Management Platform (Figure 1) collects asset data from field-based wired and wireless sensors and delivers information on the most critical situations to the appropriate personnel, enabling users to make

INTELLIGENT INSTRUMENTATION

While wireless smart devices are nothing new, providers of instrumentation are finding ways to build additional intelligence into their monitoring equipment and then tying that into simplified mobile applications which can then be relayed into "software as a service" (SaaS) systems that help coordinate targeted maintenance activities.

"The macro-trend is data," says Frederic Baudart, Fluke Connect Product Specialist with Fluke Corp. (Everett, Wash.; www.fluke.com). "Smart technologies enable teams to choose which area to collect what kind of data, with little extra effort, while SaaS platforms provide the structure for data to become meaningful enough to drive decisions and actions."

He adds that having the right data to detect changes in condition of equipment is tremendously valuable. "Teams can prioritize their workload, avoiding both failures and unnecessary planned maintenance. Integrated data streams — for example, power monitoring plus thermal images, or vibration followed by thermal — dramatically speed up decision making. The alarm features on SaaS systems alert the teams to changes in conditions while mobile workflow tools make it possible for teams to move into action. Web-based SaaS platforms allow data sharing with everyone on a team as well as between departments."

For this reason, Fluke test tools now have embedded Bluetooth radios, allowing users to instantly save measurements to SaaS platforms, via a smart device. Wireless sensors from Fluke allow technicians and engineers to leave measurement tools in place over a period of time to monitor, data log and live stream. Teams use these sensors for both condition monitoring, as well as troubleshooting complex system failures. The Fluke Connect SaaS platform (Figure 3) underlies both types of data-gathering practices, so that teams and managers have a comprehensive and meaningfully organized set of data.

Similarly, for pumps, motors and rotating equipment, the i-Alert2 equipment health monitor, a product of ITT Industrial Process (Seneca Falls, N.Y.; www.itt.com), is a Bluetooth smart device that tracks vibration, temperature and run-time hours. It also has the ability to trend information as it stores data once per hour and on alarm for 60 days, and stores the weekly average, minimum and maximum for up to five years. The monitor also has the ability to diagnose machine faults with vibration and other analysis tools and can send alarms if equipment is outside normal operating conditions (Figure 4).

"Think of it as a Fitbit for your pumps, motors and rotating machinery," says Jeff Sullivan, global product manager for Aftermarket Technology for ITT Pro Services. "Like a Fitbit monitors steps, we monitor run time. Like a Fitbit monitors sleep and heartbeat, we monitor vibration and temperature. This is essential in a chemical facility where there may be high quantities of non-critical rotating machinery that would otherwise be cost-prohibitive to monitor on a continuous basis."

"All users need to know is how to operate a smartphone and then it is possible to set up a condition-monitoring route and achieve continuous monitoring of these assets," says Dan Kernan, global product director for Aftermarket Solutions Business in ITT Industrial Process. "Chemical processors need a price-competitive product they can use to monitor their less critical pumps and machinery. In the past, if it wasn't critical, it might have been monitored every 30, 60 or 90 days, but there's a big gap of what happens between those days, so it didn't give them the insight that was needed to properly maintain these assets. Using the i-Alert2 makes it easy to inspect, analyze data and see what's going on with this type of equipment, which not only helps them make informed decisions about predictive maintenance activities, but also helps offset the loss of skilled vibration analysts and other skilled maintenance techs."

well-informed decisions regarding maintaining reliability and availability. The platform uses modern communication tools to deliver alerts to traditional desktop PCs and laptops, as well as tablets and smartphones. Remote accessibility to smart alerts in a secure environment means operators and maintenance personnel are on top of the performance of critical production assets at all times.

"Organizing and reacting to the data that are most relevant to keeping the plant running safely and efficiently is essential in today's market, where every point of availability is profit," notes Granger. "In order to achieve this, processors need automated and timely delivery of essential and relevant equipment-health information to the operations, health and safety, maintenance and production teams so that they may make smarter decisions about how they manage the facility as a team working toward reliability."

Adding to the disorganized data dilemma is that many maintenance departments have homegrown systems, says Scott Ewine, Industry Solutions Executive for ABB's (Atlanta, Ga.; www.abb.com) Enterprise Software product group. "It isn't uncommon for us to go into a plant and see that they have tools that were written by someone in the plant over 20 years ago. The siloed department puts their data into their own spreadsheet but this doesn't feed into the newer historian. There's a lot of different spreadsheets for a lot of different functions but there's no management of all this information," Ewine explains.

Schneider Electric

FIGURE 2. Maintenance Response Center from Schneider Electric offers single-window access to up-to-date information on plant-wide asset conditions and automated condition monitoring and presents the information in a common and unified dashboard for all asset notifications

Fluke

FIGURE 3. Fluke Connect Assets gives teams and managers a comprehensive and meaningfully organized set of data

He says ABB offers its electronic Shift Operations Management System (eSOMS) tool as a way to consolidate all those data points into one electronic system that is available on a mobile device so that access to information is simplified. eSOMS aids in automating and integrating the major processes of plant operations management, facilitating data sharing and reducing the amount of data entry required.

"It allows users to trend data and compare current data with historical data and make better judgments and calculations about the health of their equipment. It's a way to standardize, consolidate and share information throughout the entire plant so they can get a more holistic status of the plant and its equipment."

Doing more with less

Two of the other major challenges in the maintenance field include reduced budgets and loss of skilled technicians, which maintenance managers are overcoming via automated systems and intelligent instrumentation that help them monitor more equipment with fewer staff members and then decide how to prioritize the information and the necessary work orders.

"Maintenance is always considered a cost to the company," says Manoj Chandrasekharan, Asset Management Offer Director, Industry Business, with Schneider Electric (Andover, Mass.; www.schneider-electric.com). "But at the same time, chemical processors want to produce more product. They want to know how, in a plant that is already running at 91%, can they increase uptime by 1% with the exact same setup. They want to know how they can get more uptime and more throughput while spending less money on maintenance and reliability."

Louise Pattison, senior product manager with Meridium (Roanoke, Va.; www.meridium.com) agrees: "Because margins in the chemical industry have been very low, maintenance departments have been hampered in what they can do," she says. "They don't have the capital to invest in new processes that could help them improve maintenance and, thus, the process."

To compound matters, she says, if the process has to be stopped in order to do the maintenance, it will get deferred in all but the most critical of cases, such as definite safety issues. "The opportunities to get ahead of the game are limited by this push to get product out the door because no plant manager is going to shut down a process for maintenance unless he believes that it could lead to a bigger issue if it is not addressed immediately," says Pattison.

As a result, many maintenance departments are moving away from traditional schedule-based preventive maintenance practices and toward more targeted predictive maintenance activities. "Preventive maintenance, done on a fixed schedule, is extremely costly and

ITT Industrial Process

FIGURE 4. ITT Industrial Process's i-Alert2 equipment health monitor, a Bluetooth smart device, tracks vibration, temperature and run-time hours, trends information and has the ability to diagnose machine faults with vibration and other analysis tools and can send alarms if equipment is outside normal operating conditions

often unnecessary," says Schneider Electric's Chandrasekharan. "It requires more manpower, more time and more money to go out in the field and perform tasks on equipment that may not need maintenance just because the schedule says it does. A recent survey showed that 67% of the preventive maintenance tasks performed on process instrumentation was wasted.

"For this reason, smart maintenance departments are moving toward predictive maintenance where critical assets are constantly monitored for changes in condition so that the technicians can perform tasks on equipment when and where it is needed," he says. "This saves tremendously on labor and costs and reduces unnecessary downtime while ensuring that equipment is more reliable."

Maintenance managers decide which pieces of equipment demand attention based upon data mined from intelligent monitoring instrumentation (see the sidebar on p. 20 for more on intelligent monitoring devices). Smarter instrumentation is also often combined with software products designed to take the guesswork out of identifying critical machinery, as well as prioritizing tasks.

For instance, Meridium's APM Failure Elimination software helps users understand failure patterns and rates, predict when failures are likely to occur and plan maintenance to avoid these occurrences. This solution provides integrated and intuitive tools that offer a comprehensive approach to managing reliable production, determining the causes of failure and mitigating or preventing the causes of failure.

Meridium also offers APM Analytics, which is based upon cognitive analytics. This capability features machine-learning algorithms that identify failure patterns that may be missed through traditional analytical routines. By taking complex processes and business challenges and applying these advanced algorithms, along with data mining and analysis, cognitive analytics can aggregate all of the data being collected and provide a full view of asset health and performance.

"These solutions help departments with limited budgets and goals of increasing reliability determine what they should do by identifying what we call 'bad actors,'" explains Meridium's Pattison. "It helps identify the equipment that causes them to lose production because this is where the revenue can be found. You can shave 10% off the maintenance budget, but if you're not addressing the equipment with the most significant reliability problems that cause you to lose production, it is pointless. Instead, it's better to focus limited resources on maintaining the equipment that has the most impact on reliability of process."

According to Schneider Electric's Chandrasekharan, there also needs to be a single method of prioritizing activities. "The difficulty with monitoring a variety of equipment using today's technologies is that this often requires multiple maintenance applications and then, based upon those monitoring points, managers have to make a decision and then go through the very manual process of creating a work order," he explains. "Most other departments have a single application that takes care of their responsibilities in the plant, but the maintenance department has a bunch of disparate applications." For this reason, Schenider Electric recently launched its Maintenance Response Center (Figure 2), which offers single-window access to up-to-date information on plant-wide asset conditions and automated condition monitoring and presents the information in a common and unified dashboard for all asset notifications. Diagnostic information and activities are captured for the operational life of the asset, so users can make smart decisions based upon historical performance of a device, and comprehensive reporting indicates work order history to help reduce wasted effort and improve shift handovers and status reporting, while alerts are presented in an easy-to-understand way with actionable information attached.

"The solution provides awareness of undesirable conditions and triggers targeted actions to respond proactively to emerging problems before they become major issues," says Chandrasekharan. "Early visibility and insight into asset conditions drive a proactive, predictive maintenance approach that maximizes operational efficiency, even with limited budget and manpower." ■

Joy LePree

Analyzers

Electro-Chemical Devices

Endress+Hauser

GF Piping Systems

ABB Measurement & Analytics

Monitor hydrogen peroxide in water-treatment applications

The advanced HP80 hydrogen peroxide analyzer (photo) measures hydrogen peroxide in terms of both parts per million (ppm) and the percent solution range to support a variety of process applications. It is easy to set up and use, right out of the box with no special tools, says the company, thanks to its plumb-and-play design. The analyzer system includes a hydrogen peroxide sensor, a pH sensor, a constant-head flow-control device (to maintain the optimum flowrate moving past the sensor during sampling), and transmitter with power supply, all mounted on a PVC wall panel. The HP80 analyzer features amperometric hydrogen peroxide sensors, which are manufactured with a gold cathode, silver anode and rugged microporous membrane. The operating temperature range for these sensors is 0 to 45°C (32 to 113°F). — *Electro-Chemical Devices, Irvine, Calif.*
www.ecdi.com

Analytical transmitter helps to integrate multiple sensors

The Liquiline CM44P multichannel analyzer transmitter (photo) accepts up to 16 different parameters from six analytical sensors simultaneously, and transmits them via 4–20-mA HART, Profibus, Modbus or EtherNet/IP. It is designed to simplify the monitoring of processes, such as chromatography, fermentation, phase separation and filtration, all of which rely on multi-parameter monitoring. The CM44P accepts inputs from up to two process photometers and four analytical sensors simultaneously. Sensor types include pH, ORP, conductivity, dissolved oxygen, nitrate, turbidity, free chlorine and ion-selective sensors. Mathematical functions allow the device to calculate measured values on the basis of multiple input values, says the company. The CM44P also performs a variety of diagnostic assessments on all connected sensors and analyzers, reporting all resulting diagnostic messages according to NE107 categories, and an optional web server allows operators to remotely access the device. — *Endress+Hauser, Greenwood, Ind.*
www.us.endress.com

A turnkey option for measuring chlorine dioxide

The latest addition to this company's line of measurement and control products for disinfectant monitoring is the reagent-free Signet 4632 Chlorine Dioxide Analyzer System (photo). The system features amperometric sensing technology, a clear flow cell, flow regulator, sensors, filter and variable-area flow indicator in one compact unit. It measures chlorine dioxide levels up to 2 ppm in a variety of water-treatment applications, such as cooling towers, wastewater odor-control systems, food and beverage processing and more. The unique flow-cell design acts as a built-in flow regulator, automatically controlling the flow stream vertically across the sensor membrane, improving accuracy and allowing for inlet pressures from 15 to 120 psi (1 to 8 bars). — *GF Piping Systems, Irvine, Calif.*
www.georgfischer.com

Laser analyzer is highly selective and interference-free

The LGR-ICOS Model 950 (photo) is an online, continuous laser-based process analyzer that performs ultra-sensitive measurements of industrial trace gases, in applications including calibration, management of industrial gas blankets, tank and pipeline operations and more. It uses patented Off-Axis integrated cavity output spectroscopy (OA-ICOS) technology — a cavity-enhancement absorption technique that extends optical path lengths by multiple miles to greatly improve the sensitivity to such trace gases as CH_4, CO_2, CO, O_2, H_2S, HCl, NH_3, HF, C_2H_2, and others, says the company. The device is said to be easy to use, it requires no field

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

calibration, and has minimal preventive maintenance requirements, and continuous diagnostics and warnings help to avoid emergency repairs. — *ABB Measurement & Analytics, San Jose, Calif.*
www.abb.com

Combustion analyzer supports analysis and troubleshooting

The new EMIA-Expert carbon/sulfur analyzer is an advanced configuration model to the company's EMIA-Pro (the basic model). Both offer non-dispersive infrared (NDIR) measurement capabilities, and are equipped with a unique CO detector. They can be used for a variety of inorganic materials, such as steel, coke, catalysts, non-ferrous metals such as aluminum, and lithium-ion battery materials. New functionality on the EMIA-Expert includes a high-performance purifier unit for carrier gas for high-accuracy measurement of ultra-low-carbon concentrations. High-performance heating-unit filters prevent absorption of SO_2 by moisture created by the samples during analysis. The patent-pending cleaning mechanism on both the EMIA-Pro and EMIA-Expert clears dust in the furnace, enabling up to 200 measurements without maintenance cleaning. This increased efficiency means one measurement cycle can be completed in about 70 s, or 50 samples per hour. — *Horiba Scientific, Edison, N.J.*
www.horiba.com/scientific

Inline viscometer monitors the rheology of drilling fluids

To optimize fracturing and drilling operations, the drilling fluid's viscosity and rheology must remain be optimized. During hydraulic fracturing, the Brookfield TT-100 Inline Viscometer (photo) provides realtime, inline measurements for gels moving in pressurized lines from the hydration unit before being pumped downhole. The device continuously verifies that the fracturing fluid rheology at the well site is within established

Ametek Brookfield

specifications and provides an alarm indication when it is not. — *Ametek Brookfield, Middleboro, Mass.*
www.brookfieldengineering.com

Hybrid laser device provides continuous gas analysis

The Rosemount CT5100 continuous gas analyzer is the world's only hybrid analyzer to combine tunable

Ametek Grabner

Mil-Ram Technology

Dynatrol USA

diode laser (TDL) and quantum cascade laser (QCL) measurement technologies for process gas analysis and emissions monitoring, according to the manufacturer. The CT5100 is ideally suited for process gas analysis, continuous emissions monitoring, and ammonia slip applications, which can detect down to sub-ppm levels for a range of components, while simplifying operation and significantly reducing costs. It can measure up to 12 critical component gases and potential pollutants simultaneously within a single system. The CT5100 has a simplified sampling system that does not require gas conditioning to remove moisture. — *Emerson Process, Gothenburg, Sweden*
www.emersonprocess.com

This analyzer provides vapor pressure testing on the go

The MiniVap VP Vision is a portable analyzer and vapor-pressure tester that is designed to measure gasoline, jet fuel, crude oil, liquefied petroleum gas (LPG) and solvents, without the need to attach it to a pressure regulator. The analyzer is certified to work in cold as well as hot and damp climates, and withstands vibration and heavy shocks from any direction, says the company. These attributes make it suitable for use in mobile laboratories and demanding industrial settings. It comes with an extended pressure range of 0–2,000 kPa without compromising precision, according to the manufacturer, and its newly developed 2D-Calibration Correction Field (273 points) and exact piston-positioning (in the sampling valve) ensure accurate results and repeatability over the full measuring range. — *Ametek Grabner Instruments, Vienna, Austria*
www.grabner-instruments.com

Versatile gas detector features large graphics display

The TA-2100 (photo) is a gas detector with a large graphics display. It provides user-friendly instructions, data and bar graph display, advanced diagnostics and continuous onboard systems monitoring, and eliminates short-hand, coded messages. The gas detector measures hundreds of volatile organic compounds, as well as toxic gases, oxygen, hydrocarbons, lower explosive limit (LEL) and more, using a variety of sensor technologies (electrochemical, catalytic LEL, infrared, photoionization, solid- state and more). Continuous advanced diagnostics help engineers to meet SIL 2 requirements, according to the manufacturer. — *Mil-Ram Technology, Fremont, Calif.*
www.mil-ram.com

Wireless gas detector gains interoperability certification

The SDWL1 wireless gas detector has recently recently been certified as ISA 100 Wireless Interoperable, assuring that it will seamlessly join and interoperate in any other suppliers' certified ISA 10 Wireless networks. The SDWL1 is a wireless flammable-gas detector, built to extend the benefits of wireless detection into safety applications for which the use of traditional hard-wired devices may be cost-prohibitive or physically impossible. This helps to reduce implementation requirements and support extended coverage of gas-monitoring objectives at CPI sites and potentially reduces the need for on-site inspections. — *Riken Keiki Co., Tokyo, Japan*
www.rikenkeiki.co.jp

Device provides continuous density measurement

The Dynatrol CL 10-HY Density Cell and Series 2000 Density Digital Converter (photo) combine to provide online, continuous density measurement of numerous chemicals, such as ammonium hydroxide, caustic soda, ethylene glycol, hydrochloric acid, methanol, nitric acid, oleum, phosphoric acid, sodium chloride, sodium hydroxide and sulfuric acid. The Dynatrol Density Cell can operate in harsh industrial environments and is available in a full spectrum of corrosion-resistant materials with broad temperature and pressure ratings. The Dynatrol Density Cells are weather-tight, and are approved for most hazardous-area classifications such as CL 1, Divisions 1 and 2. There are no motors, bearings, spindles or moving parts to maintain, which ensures long, wear-free operating life. — *Dynatrol USA, Houston*
www. dynatrolusa.com ■

Suzanne Shelley

New Products

Endress+Hauser

Radar level transmitters with Bluetooth connectivity

The Micropilot FMR10 and FMR20 (photo) free-space radar level transmitters measure liquid levels in storage tanks, open basins, open channels, weirs and canal systems. The FMR10 measures liquid levels at ranges up to 16 ft with 0.2-in. accuracy, while the FMR20 measures levels up to 66 ft. with 0.08-in. accuracy. Both models offer the option of Bluetooth configuration. Protection to IP66/68 and NEMA 4X/6P, hermetically sealed wiring and fully potted electronics eliminate water ingress and allow operation under harsh environmental conditions. Both sensors are available with a flooding tube that allows a maximum output signal to be generated even if an overflow condition causes the sensor to be completely immersed. The level sensors work in process temperatures of –40 to 176°F and pressures of –14 to 43 psi, and are vibration resistant. — *Endress+Hauser, Inc., Greenwood, Ind.*

www.us.endress.com

Material Transfer & Storage

Achieve enhanced discharge flow with this portable system

The hydraulic Lift & Seal System (photo) docks drums to a gasketed pour cone for dust-tight and contaminant-free product discharge. The pour cone features 316-2b stainless-steel construction and a pneumatic turbine vibrator for enhanced product flow. The system's portable design allows for simple implementation into existing processes. The patented Control Link rotation system safely inverts the drum for maximum product discharge. Units can be custom designed for users' specific application requirements. — *Material Transfer & Storage, Inc. (MTS), Allegan, Mich.*

www.materialtransfer.com

ITT Goulds Pumps

This heavy-duty slurry pump can be serviced while running

XHD model pumps are heavy-duty metal- and rubber-lined slurry pumps (photo) that can be serviced while running, due to the presence of more accessible and adjustable parts than comparable slurry pumps, says the manufacturer. These pumps can be installed into existing pump layouts with minimal baseplate and piping changes. The XHD is used in applications such as primary metals, mineral processing, non-metallic mining, power utilities and sand and aggregates. XHD pumps operate with capacities up to 13,000 gal/min, with heads up to 280 ft at temperatures up to 250°F and pressures up to 17 bars. — *ITT Goulds Pumps, Seneca Falls, N.Y.*

www.gouldspumps.com

Analyze and edit images in the field with this infrared camera

The TiX620 infrared camera's 640×480 resolution provides measurement accuracy, and its 5.6-in. high-resolution LCD screen enables thermographers to identify issues and edit images directly on the camera while still in the field, reducing time in the office that was previously spent optimizing images and generating reports. The TiX620 provides users with EverSharp multifocal recording, which captures multiple images from different focal distances and combines them into one image, displaying each object, from foreground to background, sharply for the best image quality. Onboard advanced analytics allow users to adjust or enhance images directly on the camera without additional software. Also included is the company's SmartView software, which provides a suite of tools to view, optimize, annotate and analyze infrared images, and generate fully customizable professional reports. — *Fluke Corp., Everett, Wash.*

www.fluke.com

Omega Engineering

Measure uneven bulk solids with these ultrasonic level sensors

LVTX-10 Series close-range ultrasonic distance and level sensors (photo) are low-profile ultrasonic transmitter modules optimized to provide continuous measurement of fluids, pastes or uneven solid bulk materials in constrained working zones. Incorporating dual-sensor ultrasonic technology and processing algorithms, all LVTX-10 sensors provide accurate measurement for factory automation, warehouse materials control, pipe and conveyor belt blockage, or tank level applications with

non-uniform surfaces. LVTX-10 sensors include an advanced diagnostic feature that will retrieve the ultrasonic waveform for analysis, and display it on any computer to aid users with debugging complex installations. For solid materials, surface unevenness is unlikely to affect maximum ranging capability, says the company. An integrated mounting plate with preformed holes is provided for easy installation. — *Omega Engineering Inc., Stamford, Conn.*
www.omega.com

This particle analyzer measures over 30 different parameters

Fluid Imaging Technologies

The FlowCam 8100 particle imaging and analysis system (photo) features this company's most advanced camera with the fastest imaging speed and double the image-capture area to increase throughput and detection rates. Imaging at up to 120 frames per second, the FlowCam 8100 automatically detects thousands of individual particles and microorganisms in seconds, takes a high-resolution digital image of each one detected and measures them in realtime based on their actual size and shape. Sampling volumes as small as 200 µL, the FlowCam 8100 measures more than 30 different parameters, including particle size, concentration and advanced morphological characteristics such as circularity, elongation and fiber curl. The FlowCam 8100 includes a computer-controlled syringe pump, a quick-connect field of view (FOV) flow cell with holder and an integrated pipette-based sample port with automated rinsing and cleaning. — *Fluid Imaging Technologies, Inc., Scarborough, Maine*
www.fluidimaging.com

This syringe pump has two independent pumping channels

Harvard Apparatus

The Pump 33 DDS (dual drive system; photo) is a syringe pump that has two independent pumping channels controlled by an intuitive touchscreen interface. This multipurpose pump employs advanced syringe mechanisms that include a tight-gripping, extremely secure syringe clamp

SKF USA

BHS-Sonthofen

Compressor Products International

Neptune Chemical Pump

that accommodates syringe sizes ranging from 0.5 µL to 60 mL. The Pump 33 DDS offers enhanced flow performance with high accuracy and smooth flow at capacities ranging from 1.02 pL/min to 106 mL/min. — *Harvard Apparatus, Holliston, Mass.*
www.harvardapparatus.com

Contact angles provide benefits for these bearing arrangements

The MRC PumPac series of angular contact ball-bearing arrangements (photo) can reduce operating temperatures and vibration while helping to prevent ball sliding and shuttling in demanding pump applications, including centrifugal pumps and other systems typically subject to significant thrust loads while operating at relatively high speeds. PumPac arrangements incorporate combinations of 40- and 15-deg bearing contact angles capable of carrying high thrust loads within the 40-deg bearing without unloading the opposed 15-deg bearing. As a result, greater axial loads can be applied, and the bearing's operating temperature and vibration levels will decrease for smoother operation and longer service life, says the company. — *SKF USA Inc., Lansdale, Pa.*
www.skfusa.com

This rotary pressure filter has clean-in-place technology

Type RPF rotary pressure filters (photo) are continuously operating filters that facilitate gas-tight cake handling in a series of separate process steps. The fully automatic clean-in-place (CIP) system fulfills the stringent requirements of the pharmaceutical and food industries for cleaning surfaces inside of the machine. The filters support a broad range of process steps during a single rotation of the drum. Further processes can be carried out after separating the slurry into filtrate and filter cake, including displacement, countercurrent and closed-cycle washing, as well as reslurrying, solvent exchange, steaming, extraction and mechanical or thermal cake dewatering. All process steps are performed within the filter's segregated segment zones, making it possible to separately discharge the filtrates or other substances. The rotary pressure filter is a fully encapsulated unit that can be integrated into production processes in a gas-tight manner. This means that it is also suitable for use in operating scenarios with increased safety or hygienic requirements. — *BHS-Sonthofen GmbH, Sonthofen, Germany*
www.bhs-sonthofen.de

Condition monitoring tools for compressor-lubrication systems

The new Proflo USB-IR Adaptor (photo) and Proflo Assist Software provide condition monitoring of reciprocating-compressor lubrication equipment. They read and transfer information from the Proflo PF1 monitoring device, which records the average cycle time for each 30-min block of lubrication-system operation to a laptop, tablet or other USB-equipped device through the use of infrared technology. The Proflo Assist Software presents the cycle-time trend data, delivering condition-based maintenance capabilities. The Proflo PF1 monitors a compressor lubrication system, alerting an operator or engaging shutdown protection based on the cycle time of the system. Realtime access to this information can help technicians intervene and prevent a range of problems, including the extrusion of packing and piston rings, locking of the packing case, valve stiction and more. — *Compressor Products International (CPI), Houston*
www.cpicompression.com

A rugged low-flow pump for challenging fluids

The recently introduced Series MP7000 mechanically actuated diaphragm metering pump (photo) was designed to be a low-flow version of this company's Series MP7100 metering pump. With the ability to dose a wide range of mild to aggressive chemicals, including those used in water and wastewater treatment and chemical processing, the Series MP7000 eliminates the need for intermediate fluid or hydraulic oil to actuate the diaphragm and reduces the potential for gearbox oil to contaminate the process. Series MP7000

pumps also feature the following: a finned gearbox that readily dissipates the heat created during normal operation; oversized check valves that improve performance and minimize friction losses; and rugged bronze gears for quiet running. Additionally, the straight-through flow design of the Series MP7000 liquid end and the elimination of the contour plate result in improved flow characteristics, making the pump suitable for pumping difficult chemicals, such as viscous fluids, shear-sensitive fluids and fluids with suspended solids. Series MP7000 pumps deliver capacities to 27 gal/h and operating pressures up to 16 bars. — *Neptune Chemical Pump Co., North Wales, Pa.*
www.neptune1.com

Platinum-clad anodes available in a variety of configurations

Anomet Products

This company's line of platinum-clad anodes (photo) are metallurgically bonded and are said to be more durable and longer lasting than MMO (mixed metal oxide) counterparts. The anodes are metallurgically bonded platinum to niobium or titanium, with or without a copper core for enhanced conductivity. Featuring a dense, pinhole-free and uniform structure, these anodes provide a more uniform current distribution with lower operating current densities. Designed for electroplating processes, the anodes can be supplied as rod, wire and mesh in a variety of configurations, including precut circles and squares. Woven mesh can be up to 24-in. wide, and wire and rod can range from 0.021- to 1-in. diameter. — *Anomet Products, Inc., Shrewsbury, Mass.*
www.anometproducts.com

Quality data capture in hazardous areas made easy

ecom instruments

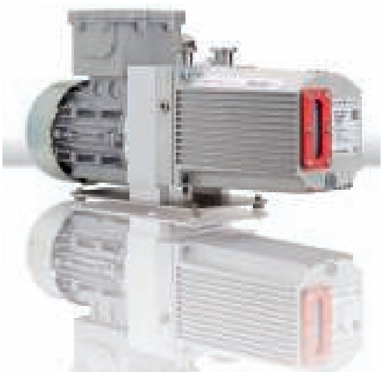
The use of 1- and 2-D barcodes and NFC/HF RFID transponders is steadily increasing. They identify items, pallets, containers, storage locations and even yard locations, and therefore help to keep track of asset movements. This company has developed data-capture software, the CamScan Keyboard App (photo), which allows — even offline — barcodes to be scanned and NFC/HF RFID transponders to be read or written using the camera of a smartphone or tablet. The ecom CamScan app is a “keyboard wedge” software utility based on Honeywell’s SwiftDecoder Mobile professional offline barcode decoding software. It uses the integrated camera of the world’s first Zone 1/21 and Division 1 certified tablet, the Tab-Ex 01, and the world’s first intrinsically safe 4G/LTE-capable Android smartphone, the Smart-Ex 01, to scan barcodes, automatically converting them to human readable text. — *ecom instruments GmbH, Assamstadt, Germany*
www.ecom-ex.com

A new series of active pulsation dampeners

The new DT series of active pulsation dampeners (photo, p. 32) is totally redesigned, and has more features and benefits than its predecessor PD. The active pulsation dampener is said to be the most efficient way to remove pressure variations on the discharge of a pump. The dampener works actively with compressed air and a diaphragm, automatically

Tapflo

WIKA Alexander Wiegand



Pfeiffer Vacuum

ABB

setting the correct pressure to minimize the pulsations. When the liquid pressure falls in the piping system, the dampener supplies extra pressure to the discharge between the pump strokes by displacing liquid by means of diaphragm movement. This pumping action created by the dampener decreases the pressure variations and pulsations. — *Tapflo AB, Kungälv, Sweden*
www.tapflo.se

New diaphragm pressure gage for the highest safety

The new model PG43SA-D diaphragm pressure gage (photo) features integrated diaphragm monitoring, and thus eliminates the risk of an undetected diaphragm rupture. The patented monitoring functionality enables the immediate indication of any rupture in the diaphragm element via a red warning dot on the dial. Thus, the otherwise usual, regular removal of the instrument to check the measuring element is no longer required. Even in the event of a diaphragm rupture, the process risk is minimized — a second barrier in the pressure-measuring instrument reliably maintains the hermetic separation between the atmosphere and the process. Furthermore, the purely mechanical pressure transmission, which excludes the risk of any contamination through the transmission fluid, and the high overpressure safety enable the PG43SA-D to be used in processes with sensitive or critical media. — *WIKA Alexander Wiegand SE & Co. KG, Klingenberg, Germany*
www.wika.com

A new magnetically coupled rotary vane pump

The Duo 11 ATEX rotary vane pump (photo), which meets ATEX directive 2014/34/EU, was introduced for processes taking place in potentially explosive atmospheres or conveying explosive gases and vapors. As such, it satisfies the most stringent explosion-protection requirements. The ATEX certification applies for both the interior and exterior of the pump. The Duo 11 ATEX is classified as equipment category 3G and temperature class T4. It can convey all gases up to and including explosion group IIC. The pumping speed is 9 m^3/h at 50 Hz and 10.5 m^3/h at 60 Hz. The Duo 11 ATEX is equipped with a frictionless magnetic coupling. As a result, the shaft seal rings that are used with other rotary vane pumps can be dispensed with. The extra safety that the magnetic coupling provides is important in explosive atmospheres: without shaft seal rings, it is impossible for media inside the pump to escape out through faulty shaft-seal rings. — *Pfeiffer Vacuum GmbH, Asslar, Germany*
www.pfeiffer-vacuum.com

Express availability services launched for motors and drives

Control Techniques and Leroy-Somer (CT & LS) have launched a new service in Europe designed to increase product availability and delivery speed to its customers. The new Express Availability service means a large range (0.09 up to 500 kW) of motors, servos, geared motors, drives, options and accessories are now available to be shipped directly to users quickly and reliably. The Express Availability program is a strong and reliable commitment to ship products in 1 to 10 working days with an optional express transport in 24 h in Europe in case of emergency. — *Emerson Industrial Automation, Control Techniques Ltd., Newtown, U.K.*
www.emersonindustrialautomation.com

Update for System 800xA Minerals Library

An updated version of this company's System 800xA Minerals Library (photo) was released last month. The latest version adds functionalities for advanced analog-loop control, further facilitating the engineering processes and widening the scope of visible information to improve situation awareness for operators. With the new loop control connection (LCC), Minerals Library 6.0/0 applies the successful concept of "intelligent objects talking to each other" to the world of loop control. The consistent linking between objects enables engineers to design complex control concepts with a standardized structured approach. The actual control strategy and dependencies between objects are directly visualized on the operator interface. LCC is available for all

existing loop-control blocks as well as for the newly added loop-control blocks for actuators, ratio, split-range and adaptive PID (proportional integral derivative) control. These elements deliver powerful functionalities ready to be used on a broad array of advanced control challenges. — *ABB, Baden, Switzerland*
www.abb.com

Determine flare-gas heat values with this mass spectrometer

The Promaxion process mass spectrometer (photo) is said to offer more detailed and relevant data faster than gas chromatography and with more specificity than calorimetry. In field tests, the Promaxion has been used to accurately calculate makeup gas values for complete combustion and monitor and quantify 16 components in a flare-gas stream, including hydrogen, nitrogen, methane, ethane, propane and more. Proprietary software allows for easy setup, operation and calibration, combined with advanced alarm and automation capabilities. The ProMaxion's modular design and self-diagnostic capabilities ensure ease of maintenance. The instrument is housed in a stainless-steel enclosure. — *Ametek Process Instruments, Pittsburgh, Pa.*
www.ametekpi.com

Blower packages available open or enclosed

The new MPAK 2000 blower package (photo) is designed for simple installation and to meet specific applications for optimized efficiencies. Features of the high-endurance MPAK 2000 include air or gas blowers, accurate blower sizing and open or closed package design with field retrofittable enclosure options. The enclosed design features a clear viewing window to check on blower oil levels. Standard gages measure pressure, temperature and filter life. The blower packages provide up to 2,200 ft^3/min flowrate, pressures up to 18 psi and vacuum down to 17 in. Hg. — *Tuthill Vacuum & Blower Systems, Burr Ridge, Ill.*
www.tuthill.com ■

Mary Page Bailey and Gerald Ondrey

Ametek Process Instruments



Tuthill Vacuum & Blower Systems

Sampling for Internal Corrosion

Department Editor: Scott Jenkins

Properly selected and executed sampling techniques are essential for assessing, controlling and mitigating internal corrosion of pipes and other assets in the chemical process industries (CPI). Key data for evaluating an asset or piping system for internal corrosion include the following: materials of construction, properties of fluids carried, operating conditions and valid analytical data from proper sampling. This reference describes considerations for sampling of internal corrosion.

Sampling methods

Internal corrosion sampling consists of several overlapping evaluation methods — some performed with the system operating normally and others performed with the equipment operated to facilitate the test method. Widely used methods for assessing internal corrosion include the following:

- Bacterial analysis
- Coupons and probes
- Deposit analysis
- Gas samples
- Liquid samples
- Inline inspections

These sampling methods can be used independently, or in combination, to determine the extent and suspected causes of internal corrosion. This information can then help determine whether mitigating methods are necessary, as well as whether or not the mitigation measures were successful. Common potential causes of internal corrosion include acid gases (CO_2, H_2S), bacterial corrosion, erosion corrosion or a combination.

Liquids

These corrosion tests for liquids are prioritized to allow the most accurate field analysis:

1. Presence of water
2. pH
3. Temperature
4. Dissolved CO_2
5. Dissolved H_2S
6. Alkalinity
7. Bacteria density

The presence-of-water test is performed using a type of litmus paper.

FIGURE 1. Weight-loss coupons are installed for a period, then weighed to determine corrosion

If the liquid being sampled is composed only of hydrocarbons, no further testing would be necessary. After confirming that the sample contains water, the pH and temperature of the sample should be measured. Next, the dissolved gases and alkalinity should be tested. Finally, the sample should have a bacterial dilution series set up. These onsite tests should be performed as quickly and safely as possible, preferably within 15 min of taking the sample. Bacteria must be inoculated within 4 h of sampling.

Solids

The following list for testing solids can be used whether the solid material was blown out of the pipeline, obtained from a pigging run or obtained by separating the pipeline:

1. Appearance of the solids
2. pH
3. Bacteria density
4. Onsite chemical testing

When air is introduced into a pipe, the piping material begins to oxidize, thus changing the chemistry of the solid material. So the solid material should always be visually inspected as quickly as possible, before oxidation occurs and changes the appearance of the solid material. Then pH testing should be performed, along with processing the solid for bacterial analysis, as this material can be a breeding ground for bacteria. Finally, any additional onsite chemical testing can be performed. The sample should then be placed into a container that minimizes the amount of airspace to slow the oxidation of the sample.

Gases

For gas sampling, the following onsite tests can be performed with stain tubes for water vapor and acid gases:

1. Water vapor
2. Acid gases
3. Temperature
4. Pressure

When sampling for laboratory analysis of acid gases, the type of container is important. For CO_2 and O_2, standard carbon-steel cylinders can be used, but if H_2S is to be analyzed, the sample cylinder needs to be lined or treated so that the cylinder itself does not react with the H_2S and corrupt the sample analysis. Also, when using sample cylinders, the pressure rating should be sufficient to handle the pressure in the system being sampled. Gas sample locations should be in areas that are representative of the system, and need to be accessible for repeat sampling. Care should be taken to avoid liquids (water or liquid hydrocarbons) in the sample cylinder to prevent damage of the analytical equipment.

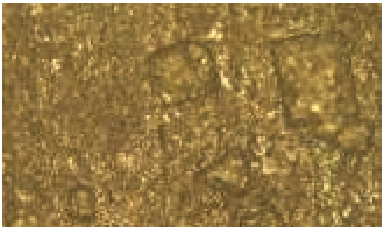


FIGURE 2. Evaluating and monitoring coupons can assess micro-pitting on a metal surface

Coupons and probes

Coupons and probes are also used to measure potential corrosion in pipelines. Coupons can be basic weight-loss coupons, where a clean known-weight metal coupon is installed into the pipeline for a period of time (Figure 1). The coupon is removed, cleaned and reweighed, and a calculation is performed to yield weight loss over time. A more advanced approach is to use evaluating and monitoring coupons, which have a specially prepared smooth surface designed for microscopic analysis and used to evaluate micro-pitting (Figure 2). ■

Editor's note: This edition of "Facts at your Fingertips" was adapted from the following article: Rine, J., Internal Corrosion Sampling, *Chem. Eng.*, July 2012, pp. 26–29.

Carbon Fiber Production from Pitch

By Intratec Solutions

Carbon fibers (CF) are defined as fibers containing at least 90% carbon by weight, obtained by pyrolysis of an appropriate precursor fiber. Their properties, such as high stiffness, large tensile strength, good chemical resistance, light weight, high temperature tolerance and low thermal expansion, make them suitable for a range of applications including aerospace and sporting goods. Carbon fibers are also used for chemical protective clothing, electromagnetic shielding and as fire-retardant nonwoven materials.

The main precursor fibers used to manufacture carbon fibers are polyacrylonitrile (PAN), petroleum/coal pitch and synthetic cellulosic fibers (for example, rayon). The precursor material for CF is of major importance because it dictates the fiber properties, as well as how the fiber behaves mechanically, physically and chemically. In fact, a wide diversity of fibers, having different specifications, can be obtained from different raw materials and different production processes.

The process

The production process for high-modulus carbon fiber from pitch is described in the following paragraphs and shown in Figure 1.

Pitch treatment and spinning. The first step in the production of pitch-based carbon fiber is pitch treatment, in which the petroleum pitch is converted into a liquid crystalline phase called mesophase pitch, with adequate spinnability. The treatment involves heating the pitch at 350–450°C using a mixture of oxygen and nitrogen for sparging. The mesophase pitch is cooled down and solidified, and then melt-spun into pitch fibers. The mesophase pitch spinning is performed by melt extrusion.

Stabilization, carbonization and graphitization. The thermoplastic pitch fiber thus obtained is oxidized into infusible thermosetting fibers by means of gas-phase oxidation, at 250–400°C. This stabilization (thermosetting) aims to prevent softening and resulting deformation of the pitch fibers upon heating downstream. After stabilization, the pitch fibers are carbonized in a multi-zone furnace, under an inert atmosphere, in successive heating zones with temperatures increasing from 700 to 2,000°C. The goal of the carbonization is to remove elements other than carbon from the fibers, and to grow graphite crystals (graphitization). The carbonized fibers are then heated to higher temperatures (2,500–3,000°C), in order to promote growth of the ordered structure, increase crystalline orientation in the fiber direction and reduce the interlayer spacing (increasing carbon fiber's tensile modulus of elasticity).

Surface treatment and sizing. The carbon fibers are submitted to anodic oxidation (electrolytic bath), so as to roughen the filaments' surface and introduce functional groups into the fiber surface (improving interfacial fiber-matrix bonding). The carbon fiber is then coated with a solution of resin, to protect it in downstream operations and keep filaments adhered together in individual tows. Finally, the carbon fiber is wound onto bobbins and stored.

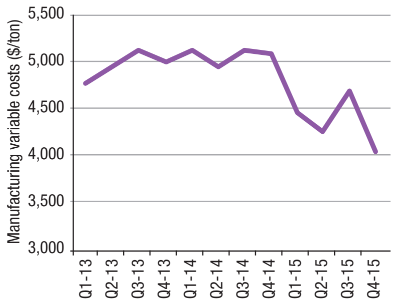


FIGURE 2. CF variable costs have changed over time

Economic performance

The direct process costs associated with the "stabilization, carbonization and graphitization" steps, described above, of a plant with capacity to produce 500 metric tons per year of pitch-based carbon fiber in the U.S. is about $6 million (data from the fourth quarter of 2015). The cost represents the investment required for the equipment purchase and installation (including installation bulks). The manufacturing variable costs (raw materials and utilities) are about $4,100 per ton of pitch-based carbon fiber produced. Figure 2 shows the evolution of manufacturing variable costs from 2013 to 2015.

This column is based on a report published by Intratec titled "Carbon Fiber Production from Pitch — Cost Analysis." The report can be found at: www.intratec.us/analysis/carbon-fiber-production-cost. ■

Edited by Scott Jenkins

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

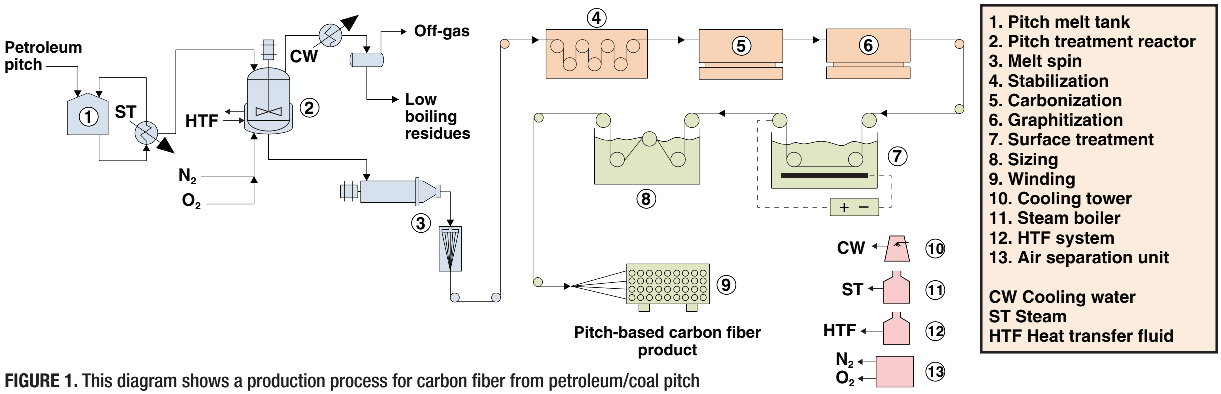


FIGURE 1. This diagram shows a production process for carbon fiber from petroleum/coal pitch

Communication Technologies for Throttling Valve Control

Closed-loop control performance depends on the dynamic response of the controller, valve, measurement and process. Can wireless compete with conventional networks?

Terry Blevins and Kurtis Jensen
Emerson

IN BRIEF

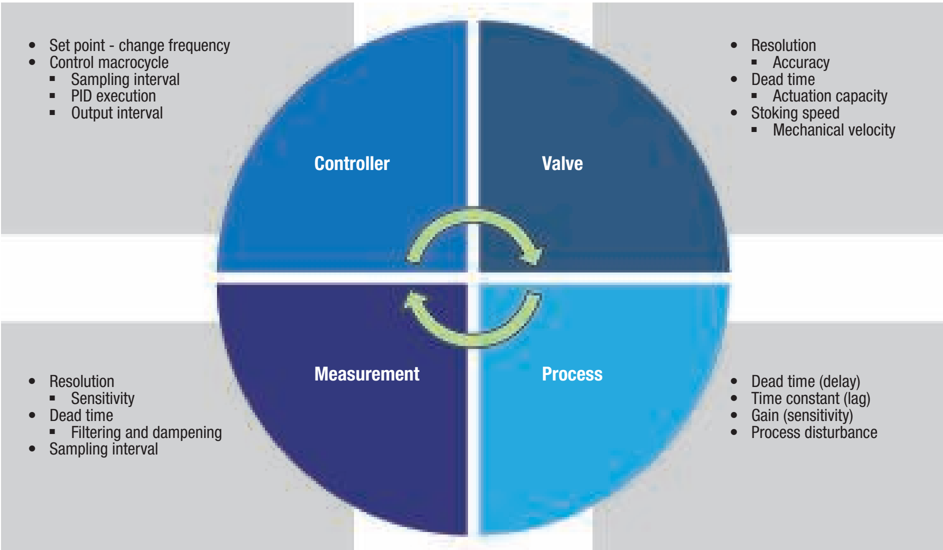


FIGURE 1. Several factors can affect the performance of the control loop for a throttling valve

When using throttling valves in closed-loop process control, a variety of factors impact the selection of the most appropriate communications network. Chief among them are performance and installation cost.

Within the chemical process industries (CPI), three networking technologies are commonly used to interface throttling valves with the automation system: 4–20 mA with HART, fieldbus and wireless. This article examines these three options, and also provides information on emerging technologies to improve control performance.

Factors affecting control performance

Performance in a closed-loop control application depends on the dynamic response of the controller, valve, measurement and process (Figure 1). To achieve a target control objective, it is necessary to consider all of these components (see box, p. 37).

Performance and cost discussions should always start with the process, but care should be taken not to focus on one area and exclude others. For example, the valve should be considered along with the rest of the process-loop elements to achieve operating objectives. There are three main criteria that may be used to evaluate closed-loop throttling-valve control: process variability, reliability and control responsiveness.

Reduced process variability can provide a competitive advantage in manufacturing and can lead to higher operating profits. As an example, some processes have a maximum allowable operating pressure (MAOP, Figure 2), and the closer to the MAOP that the process operates (without exceeding MAOP), the higher the profit. By reducing process variability, it is possible to operate closer to the MAOP.

To reduce variability, the valve and associated positioning technology must meet current and future needs. For example, the goal may be to achieve a resolution in valve movement of 2% of span today, but future continuous improvement projects could require a resolution of less than 0.25% of span. This will rule out current-to-pressure (I/P) transducers and electro-pneumatic positioners, because they cannot perform at this level of reduced variability. Digital valve positioners will be required, as they do a much better job of overcoming backlash and static-friction (stiction) issues.

If a valve experiences vibration and is not performing as needed, examine the position feedback technology and eliminate linkages. For the valve assembly, review the specifications and verify that it can meet your needs today and in the future. Remember that the process sensor and transmitter accuracy must also meet requirements.

Reliability refers to the integrity of the components involved with the control loop and the fail-safe behavior of the valve. Single points of failure can compromise the availability of the process loop. Redundancies in equipment can be used to eliminate critical concerns and increase mean time between failures. This approach is common in safety integrity level (SIL) design and can be used in general process design, but redundancy does increase cost.

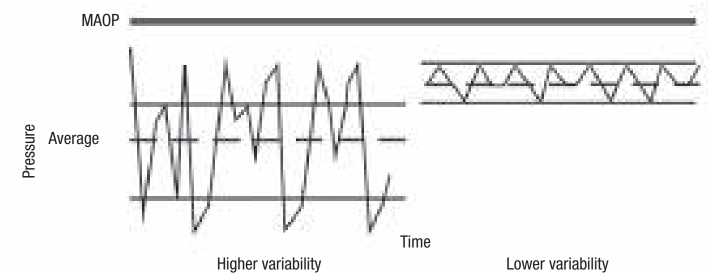


FIGURE 2. Operating a process close to the maximum allowable operating pressure (MAOP) can mean maximizing profits

Responsiveness relates to the capabilities of all the components in the control loop. These include the sensitivity of the process sensor to the resolution accuracy of the valve. Each component should be examined, with priority assigned to addressing those with the greatest impacts. For example, a process sensor with a 1%-of-span resolution and a valve assembly that can modulate with a resolution of 5% of span would suggest making valve improvements first, as these would have the greatest positive impact on variability.

Networking technologies can also impose limitations, with an example being the frequency of measurement update and control-loop execution. This may limit how quickly the control can respond to unmeasured disturbances. Delays introduced into the control loop involve the entire processing cycle — from process sampling, to calculating, to delivering output. The total delay time is important because it directly influences control performance and may affect controller tuning.

VALVE AND POSITIONER TECHNOLOGY

Control valves may be the most important part of a control loop, but sometimes they are the most neglected. They are a leading cause of process variability and poor control in loop performance.

Improvements aimed at the process or equipment require understanding important aspects of throttling valve control. Variability and responsiveness are the most sought-after improvements, and both demand a digital valve solution with position feedback technologies to deliver better accuracy, and to address stiction and backlash.

Travel deviation, drive signal and cycle accumulation alerts indicate when a valve needs attention. One test in particular — the step response test — will analyze how a valve responds to small step input changes (Figure 3). For example, a valve requiring a 5% input change to move would be a clear target for improvement.

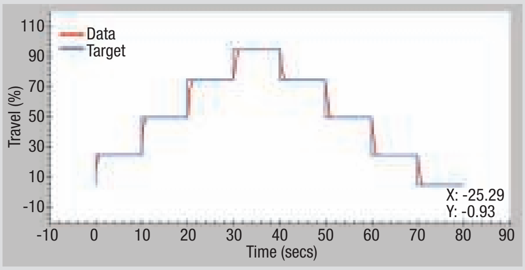


FIGURE 3. A step-response test measures how a valve responds to small input changes

Digital valve controllers offer several advantages, including the following:

Start-up and commissioning. Digital instrumentation includes the ability to perform auto-calibrations. The result is every valve is commissioned the same, eliminating differences introduced by personnel, and commissioning is completed faster.

Operating mode. If the valve positioner has a problem, it can switch modes (for example, changing from position feedback to pressure feedback). If it does, the benefit is continued operation and corrective actions started sooner via an alert sent to maintenance, preferably before process variability is affected.

Maintenance mode. When placing the control valve in a state that does not act on a signal from the control system, the automation system must be aware. If a service technician performs maintenance on a valve, he or she may place the valve in an "out of service" state and perform requested actions. Performing a calibration on a valve is one example of a maintenance task where this is helpful. During this period, the automation system should have an indication that the valve will not respond to the target output, which can be easily provided by a digital valve positioner.

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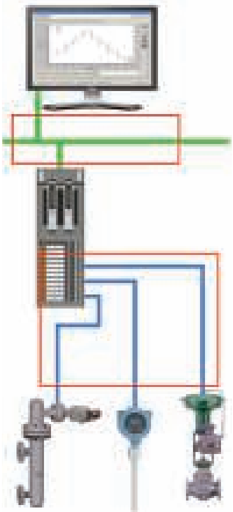
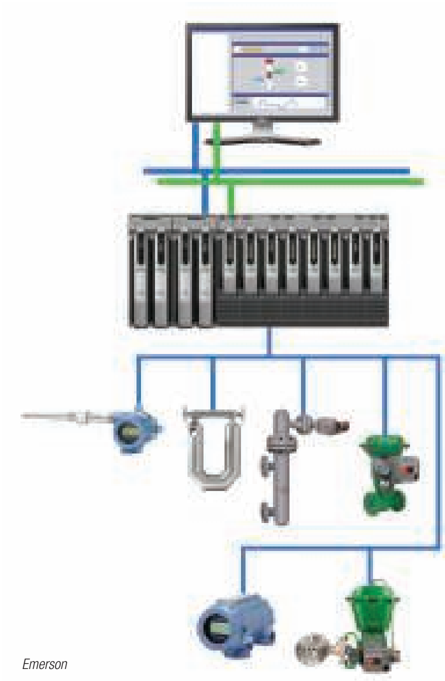


FIGURE 4. A 4–20 mA with HART connection requires a two-wire twisted pair from the I/O to the transmitter and valve, and a connection from the I/O to the controller. Potential points of failure are enclosed by the red boxes

FIGURE 5. Fieldbus is a digital communication system allowing multiple devices to connect on a segment. Redundancy options decrease failure points and improve integrity



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The three main networking technologies used in the CPI for interfacing the automation system to field devices are:

- 4–20 mA with HART
- Fieldbus (Foundation Fieldbus or Profibus PA)
- WirelessHART

An examination of each shows both advantages and concerns.

4–20 mA with HART

Plants constructed in the 20th century are, in most cases, instrumented with field devices interfacing to the automation system using 4–20-mA current signals for both measurement and control. These field devices typically have digital electronics and support HART communications superimposed upon the 4–20-mA signal.

HART communications is relatively slow (1,200 baud — units for pulses per second), so the 4–20-mA interface is typically used for process measurements sent to the automation system by field devices, and for control signals sent to throttling valves by the automation system. HART communications is typically used for diagnostics and calibration.

To avoid disruption of HART communications, the rate of change in the current signal is normally limited by the transmitter and digital valve positioner. For example, the transition time for a change from 4 mA to 20 mA may require 120 milliseconds (ms). From a practical standpoint, this limitation on rate of change has little or no impact on closed-loop control.

The rate at which the transmitter updates the 4–20-mA signal to reflect changing process conditions, the rate at which the automation system accesses the transmitter's 4–20-mA signal, and any delay introduced in processing the 4–20-mA control signal to a valve can directly impact the closed-loop control of fast processes, such as liquid flow or pressure. These delays add up and can directly impact PID (proportional-integral-derivative) control performance.

For example, when transmitter, controller I/O (input/output) scan rate, position update rate and automation system controller-output process time are each 50 ms, then a maximum delay of 200 ms and average delay of 100 ms may be introduced. Some transmitters, controllers and valves provide even slower update rates, and the resulting delay can degrade the control of fast processes. The transmitter, controller and valve positioner should be carefully selected based on their update rate when addressing control of fast processes.

With 4–20-mA control configurations, there are several single points of failure: from the controller to the I/O; the I/O itself; and the wiring from the I/O to the sensor or controller (Figure 4). Any single failure will affect the operation of a closed-loop process control structure.

When installing wiring for 4–20 mA with HART, a cable consisting of a single twisted pair of shielded wires is required for each measurement or valve. Dedicated wiring to each field device limits the impact of a short-circuit or opening in the wiring to one device. The costs of the cable, labor to install the cable and checking out each wiring connection between a field device and the automation system are significant.

In some cases, the cable cost and installation labor may be reduced by using multi-conductor cable between the automation system controller and a junction box in the field. These savings are often offset by the increased time required to document and check out the additional junction box connections. Alternatively, some controllers are designed to allow I/O cards to be remotely mounted, but the cost of providing a housing to adequately protect the I/O cards while allowing maintenance access may far exceed any savings in cable cost.

Cost and performance considerations for 4–20 mA with HART include the following:

- The technology is very mature and its operation is deterministic, providing solid performance. The overall loop execution period depends mainly on the automation system vendor and can range from 20 ms to several seconds
- HART communication can be used for diagnostics and calibration, but the 4–20-mA current signal should be used in control applications
- Loop integrity can be considered low with a single pressure sensor, single analog input, single PID controller, single analog output and single valve positioner. Adding redundancy is difficult and expensive
- Diagnostics and alerts provided by

HART-enabled devices can help plant operators detect problems quickly, sometimes before they occur, and help transition from reactive to proactive maintenance

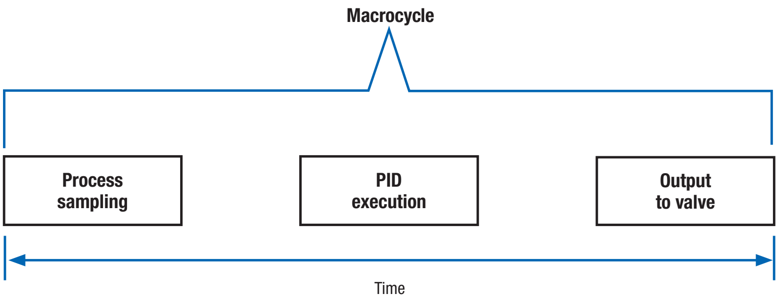

FIGURE 6. When a fieldbus device performs sampling and control in the field, the macrocycle (time to perform the entire operation) is very fast (about 55 ms)

Foundation Fieldbus and Profibus PA

Soon after 4–20 mA was approved as an international standard, work started on a fieldbus standard to support total digital communication with field devices. The International Electrotechnical Commission (IEC; Geneva, Switzerland; www.iec.ch) international fieldbus standard IEC61158 defines a physical layer for digital communications over existing twisted pair wiring installed in a plant. Various fieldbus communication protocols are defined in this standard.

The reasons for the wide acceptance of fieldbus in new plant construction include the following:

- A single twisted pair of wires may be used between a controller and junction box and then fanned out to multiple field devices (Figure 5). The wiring savings are significant compared to a 4–20-mA installation
- All field devices on a segment communicate and receive power over a single twisted pair connection to the controller, eliminating the need to supply power to each device separately
- As devices join the segment, the factory tag for the device is available to commission the device. Wiring checkout is faster, with wiring mistakes minimized
- All the measurement values available in a device — such as pressure, mass flow, temperature and other parameters in a Coriolis flowmeter — may be accessed through the digital

WIRELESS CONTROL FOR A DIVIDED WALL COLUMN

For the past six years, the University of Texas at Austin's Separation Research Program has been studying the use of wireless technologies in a dividing wall column (DWC) distillation process. At the University of Texas installation (Figure 7), column temperature, tray level and flow measurements are made using WirelessHART transmitters.

Closed-loop control using wireless temperature measurements, steam flow, liquid flow is accomplished using PIDPlus. Heater temperature control is based on PIDPlus, and temperature measurement is provided by a WirelessHART transmitter.

PIDPlus provides effective control using the typical wireless update rates of eight to sixteen seconds, which are required to achieve a five- to seven-year battery life. It is possible to control using wireless measurements while delivering performance comparable to traditional wired transmitters and wired final control elements in certain applications. The modifications in PID introduced by PIDPlus are designed to handle loss of communication, and to enable control using relatively slow measurement and non-periodic measurement updates.

The control design implemented on the DWC at the University of Texas has proven to be effective in providing stable column operation. Experience with the column operation over a variety of operating conditions has shown the following:

- Closed loop control using wireless measurements and PIDPlus effectively addresses relatively fast processes, such as liquid flow and steam flow, as well as slower processes, such as temperature control, using an eight-second periodic communication update rate
- Model predictive control satisfies process control requirements using wireless instrumentation. For the DWC control, model predictive control has been shown to outperform single loop control

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FIGURE 7. The divided wall column at the University of Texas at Austin's Pilot Plant is controlled using WirelessHART networking technology

communications link

- Valve-stem position feedback is available from a digital valve positioner
- The maximum distance between the controller and field device is comparable to 4–20-mA installations.

Fieldbus supports quick access to operational and diagnostic information in a field device. Also, the entire control loop may be moved to the field devices with Foundation Fieldbus to implement control in the field. Function blocks used for control are automatically scheduled, resulting in deterministic and synchronized control execution.

The macrocycle is the time it takes to process the input, perform the PID calculation, and then develop the output. There are differences in products affecting both the macrocycle and loop execution period.

For example, in a typical control loop where measurement and control are done in the fieldbus transmitter, there is only a 55 ms delay between measurement availability and control action initiated in the valve (Figure 6).

Thus, by using control in the field, it is possible to achieve control performance comparable to 4–20-mA devices and networks. When control is performed at the automation system instead of in the field (Figure 8), an added delay is introduced in the control loop since the measurement, control and output to the valve are not synchronized.

When addressing faster applications, this additional delay can degrade control performance. Also, as more devices are added to a fieldbus segment, the macrocycle may be extended, which can affect how quickly the control can respond to a process disturbance.

The added cost of a fieldbus device versus an equivalent 4–20-mA device is offset by the significant wiring savings, and by the reduction in the time to engineer, install and check out a fieldbus installation. Also, expanded diagnostics available with fieldbus devices can reduce the time required to resolve an operational problem.

But in a fieldbus installation, different tools and knowledge are required to achieve benefits. Thus, in a new installation, personnel involved in installation and checkout must be trained on the proper methods required to install and commission fieldbus devices. Changes will be required in the tools used to engineer and document the automation system wiring and installation.

Cost and performance considerations for Foundation Fieldbus and Profiibus include the following:

- Fieldbus technology and its operation is deterministic, providing solid performance
- The overall loop execution period can range from less than 100 ms with control in the field, to several seconds with control by the automation system for more complex designs having multiple devices per segment. Thus, the number of

FIGURE 8. When control is accomplished in the control system, additional delay is introduced because control actions are not synchronized with fieldbus processing

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devices on a segment should be limited when addressing control of fast-reacting processes

- Loop integrity can be considered low with a single pressure sensor, a single analog input, a single PID controller, a single analog output and a single digital valve positioner. Redundancies at the control system interface and elsewhere can be added to increase loop integrity
- Diagnostics and alerts are included in devices to enable proactive maintenance practices, but the amount of information sent on the fieldbus link will increase macrocycle times
- The installation and total installed costs can be 30–40% less than with 4–20-mA wired technology. This includes savings on engineering, cabling and system devices

WirelessHART

In an existing plant, installation of a new transmitter or valve may be quite costly when new wiring must be installed, and installation time may be excessive. WirelessHART devices (Figure 9) address these issues.

In new plant construction, many manufacturers find that installation and commissioning costs can be reduced by using WirelessHART field devices. When installing field devices in remote locations, such as in waste- and water-treatment areas, significant savings may be realized by eliminating wiring. The market for WirelessHART has grown significantly, leading to interest in using wireless for closed loop control.

WirelessHART field-device transmission can be slow. In particular, battery-powered transmitters may be configured to transmit only periodically — such as every 8 s — to achieve a battery life of five to seven years. For this reason, many engineers have been using wireless more for monitoring, and consider wireless too slow for control purposes.

But WirelessHART devices powered locally do not have the disadvantage of a slow update time. Update rates can be much faster, because there is no battery life concern. Energy harvesting devices that convert temperature or vibration to power can also allow WirelessHART devices to transmit at a faster rate.

In a WirelessHART network, all communications are scheduled by the WirelessHART

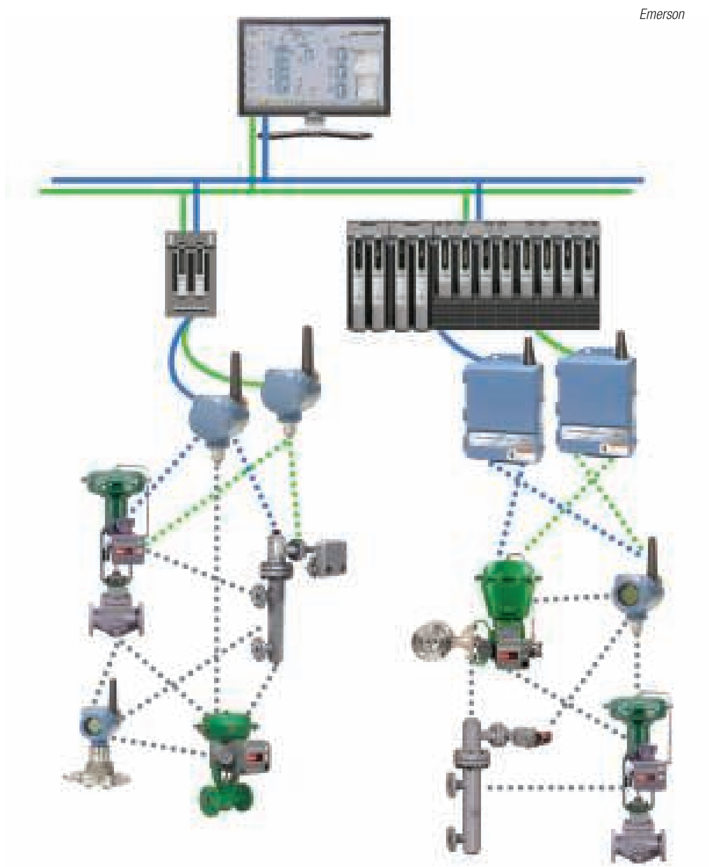
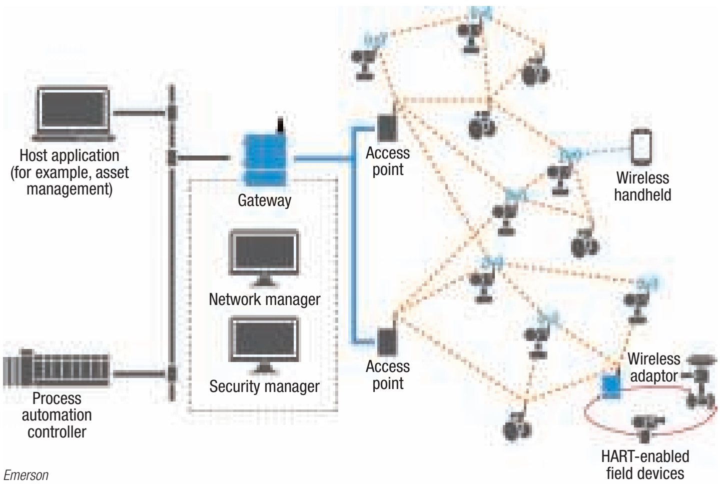


FIGURE 9. WirelessHART devices do not require a wired infrastructure. Redundancy can be added easily

FIGURE 10. A WirelessHART system is controlled by a network manager, ensuring deterministic update of the process measurement



network manager (Figure 10). The result is the deterministic update of a measurement used in process control. In other words, whatever measurement update time is required, the network manager will schedule it, within the limits of the technology.

To address control of processes with a response time of 30 s or less — such as liquid or gas flow — a modified version of the PID algorithm called PIDPlus can be used. PIDPlus modifies the PID algorithm to automatically account for slower update times. Thus, processes such as liquid or gas flow may be effectively controlled using a measurement communication update rate of 8 s.

Research at the University of Texas (Austin; www.utexas.edu) has shown that real-time control of a dividing-wall distillation column using PIDPlus and wireless transmitters is comparable to control achieved using PID control with wired transmitters (see sidebar, "Wireless Control of a Distillation Column").

For control valves, a WirelessHART adapter installed on a digital valve positioner (see Figure 10, lower right) enables wireless closed-loop control. However, the downstream communications by WirelessHART gateways are currently not scheduled and may introduce significant delay. Thus, closed-loop control using WirelessHART adapters on the throttling valve is currently limited to slower processes, such as tank level control. This will soon change with the addition of scheduled downstream communication to WirelessHART gateways.

Cost and performance considerations for WirelessHART include the following:

- WirelessHART technology for process measurements is deterministic, providing solid performance
- WirelessHART addresses integrity concerns with several levels of redundancy due to the characteristics of its wireless mesh network
- Control execution in the automation system should be much faster than the measurement-communication update rate to minimize any delay for a new measurement being used in control
- The process-sensing update rate will affect performance and battery life. For example, to achieve a five- to seven-year battery life, a communication update rate of eight or sixteen seconds may be required. There are differences in products and vendors that affect both the update frequency and battery life. This technology is changing fast and these times are expected to improve
- Valve-stem position feedback is available from a digital valve positioner
- Loop integrity can be considered low with a single pressure sensor, a single process input, a single PID controller and a single valve positioner. However, redundancies can be added to increase loop integrity
- Diagnostics and alerts, such as low battery power remaining, are included in devices to enable proactive maintenance practices
- Total installed costs can be up to 90%

less than with 4–20-mA wired technologies, and less than with fieldbus networks. These costs include engineering, cabling and system device expenses
- The number of devices on a wireless network may affect update rates

Comparing interface technologies

Table 1 summarizes the characteristics of valve control with 4–20 mA with HART, fieldbus and WirelessHART. The fastest measurement update rate is provided by 4–20 mA with HART, and the slowest update rate is provided by WirelessHART. However, it is possible to provide comparable control performance using a modified PID algorithm.

The most expensive solution is 4–20 mA with HART because of the extensive wiring infrastructure needed, and the least expensive is WirelessHART because it does not need a wired infrastructure.

While the table shows the typical communication update rates is 8 s to provide a 5–7-year battery life, this update rate can be set much faster when powered wireless field devices are used.

TABLE 1. COMPARING INTERFACE TECHNOLOGIES

Interface technology comparison	4–20 mA with HART	Fieldbus	Wireless
Measurement update rate	50 ms	100 ms to several seconds depending on the number of devices on a segment	8–16 s typical
Total installed cost	Base	30–40% lower	Up to 90% lower
Communications integrity	Low	High	High

Future enhancements

Quickly evolving and advancing areas are wireless for control and an all-digital control structure. Improvements and progress have been made recently, including advances in control algorithms such as PIDPlus. Intelligence in field instruments is now being leveraged so controllers act only when needed, which enables effective control using slower update rates.

Another area of progress is pushing more intelligence to field devices. Fieldbus-based technologies include control in the field already, but much more can be done in this area by increasing use of this capability.

HART-IP (internet protocol) will be an interesting technology as it evolves and enables greater speed and bandwidth. The underlying physical structure is independent and can be applied to multiple communication technologies such as Wi-Fi, Bluetooth and fiber-based structures.

Digital communications can eliminate the need for field devices and control system I/O to perform many A/D (analog to digital) and D/A (digital to analog) conversions. Increased use of digital communications will reduce the need for 4–20-mA field instruments.

With the increase in intelligence, new modes of operation will evolve. Digital intelligence will bring with it the ability to use "triggers." These triggers and how long they exist will be used to make value-added decisions. For example: if the target set point from the automation system has not been seen by a field-based device for an extended period of time (meaning a potential loss of communications), the valve can be smart enough to move to a pre-determined setting. Likewise, if and when the failure trigger goes away, the valve can follow pre-determined scenarios before returning to normal operation. The result will increase the integrity of process control.

When you consider a new digital-only environment, there are many opportunities for improvement that will translate into higher equipment reliability, reduced process variability and cost reductions.

Concluding remarks

Throttling valve control has relied on 4–20 mA with HART and fieldbus interfaces for decades. Wireless adapters are available today for use with digital valve positioner, and wireless field devices are also available. However, the delay introduced by wireless downstream communications limits the use of wireless valve positioner to control of slower processes. As scheduled downstream communication support is added to WirelessHART gateways, wireless throttling valves will increasingly be used in the control of faster processes. ■

Edited by Scott Jenkins

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Heat Transfer in Wiped Film Evaporators

Simulations demonstrate the complex, changing properties of materials within the evaporator. Such information can help in both designing and selecting the proper evaporator

Daniel Bethge
GIG Karasek

IN BRIEF

- WIPED FILM EVAPORATORS
- HEAT TRANSFER EQUATIONS
- SIMULATION
- WIPING TECHNOLOGY
- SEPARATION EFFICIENCY

A wiped film or agitated thin-film evaporator is very effective with difficult-to-handle materials. The evaporator consists essentially of a sealed cylinder that is provided with a heating jacket. The feed material is distributed on the inside as a thin film by means of a mechanical system. Due to the heating and the applied vacuum, the volatile components are evaporated and liquefied in an external condenser. In a short-path still, the condenser is fixed concentrically inside of the evaporator, so that a distillation at fine or even high vacuum is possible. A special version of the film evaporator is the horizontal dryer, where the material is conveyed with special conveyor elements through the evaporator. The non-evaporative components are pumped as a residue or discharged as powdery solids.

The evaporation process is mainly heat transfer controlled. For a simulation, the evaporator is advantageously divided into several zones. Using a database that is stored in simulation programs, heat transfer coefficients and temperature differences for each section can be determined. An accurate thermal design is the result, as will be explained with three examples.

Wiped film evaporators

The basic setup of a wiped film evaporator is shown in Figure 1. The feedstock is fed at the top at a constant rate and is equally distributed on the inside of the cylinder as a thin film by means of a rotor equipped with wiping elements. Feedstock flows down due to gravity. The application of heat (in this case, steam) and vacuum causes the light volatile species to evaporate. The vapors are sucked through the vapor nozzle into a rectifier, or directly to a condenser where they are liquefied. The non-volatile components are discharged as residue.

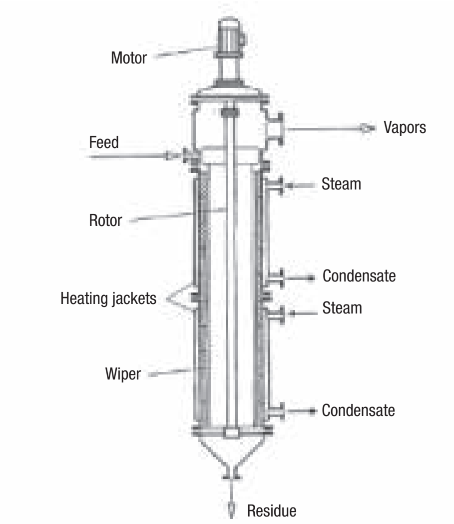


FIGURE 1. Shown here is a cross-section of a wiped film/agitated thin-film evaporator [2]

Wiped film evaporators are used for demanding evaporation processes, such as the recovery of valuable substances, the removal of solvents, the concentration of residues and so on. During the evaporation processes, the material changes its texture, for example, from a thin, watery liquid to a pasty, or jelly-like, or even powdery consistancy. The heat transfer changes accordingly.

Heat transfer equations

The heat flow, $\dot{Q}$, across the heated wiped-film area, A, is given by Equation (1):

$$\frac{\dot{Q}}{A} = U \times \Delta T \quad (1)$$

Where ΔT is the temperature difference between the heating medium and the film, and the heat-transfer coefficient (U-value) is de-

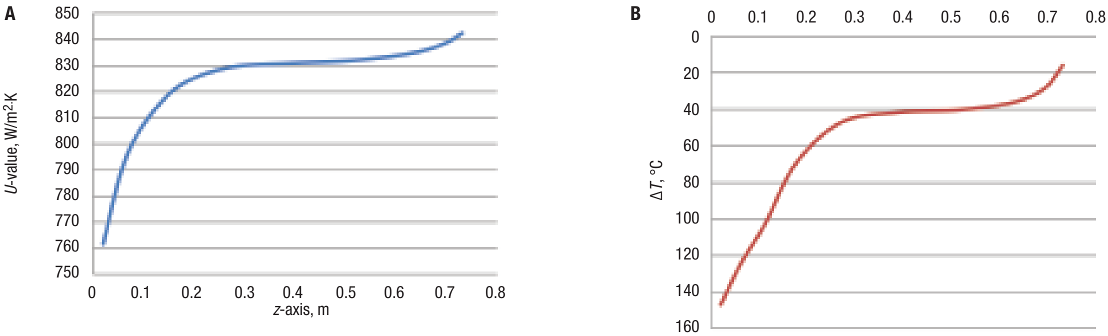


FIGURE 2. These graphs show simulation results for Example 1. Graph A (left) illustrates how the calculated *U*-value varies along height, *z*, of the evaporator (top, $z = 0$ m; bottom, $z = 0.75$ m). Graph B (right) shows the calculated ΔT as a function of *z*

fined by Equation (2):

$$\frac{1}{U} = \frac{1}{\alpha_h} + \frac{s_w}{\lambda_w} + \frac{1}{\alpha_L} + R_{fouling} \qquad (2)$$

Where:
α_h = heat transfer coefficient of the heating medium
s_w = thickness of metallic cylindrical wall with inside diameter, d_i ($d_i >> s_w$)
λ_w = heat transfer coefficient of the wall
α_L = heat transfer coefficient on the product side
$R_{fouling}$ = loss of heat transfer due to fouling

The heat transfer coefficient of the heating medium, α_h, usually amounts to at least 4,500 W/(m²·K). For a cylinder made of stainless steel, λ_w =15 W/(m·K). The heat transfer on the product side, α_L, is given by the law of Billet [1], described by Equation (3):

$$\alpha_L = K \times \sqrt[3]{d_i \times n_r} \times \frac{\lambda_L}{\sqrt[3]{\eta_L}} \qquad (3)$$

Where:
K = equilibrium constant, dimensionless
n_r = rotor speed, rpm
λ_L = thermal conductivity of the liquid
η_L = dynamic viscosity of the liquid
Normally, K = 500 if d_i is in millime-

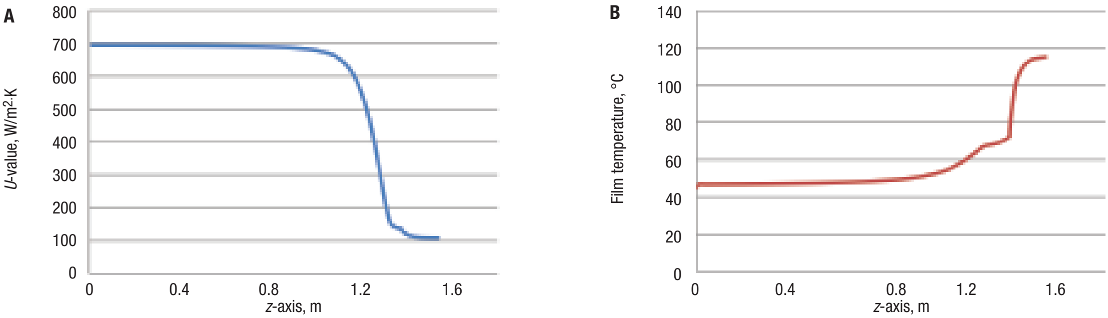


FIGURE 3. These graphs show simulation results for Example 2. Graph A (left) illustrates how the calculated *U*-value varies along height, *z*, of the evaporator (top, $z = 0$ m; bottom, $z = 1.6$ m). Graph B (right) shows the calculated film temperature, *T*, as a function of *z*

ters, but in practice the observed values are smaller, so K = 250 is used in this study.

The $R_{fouling}$ term in Equation (2), describes the loss of heat transfer due to fouling. Fouling occurs in foods, proteins and other applications when hard layers form on the surface. The layers reduce the efficiency of heat transfer. A typical value is $R_{fouling}$ = 0.0002 m^2·K/W.

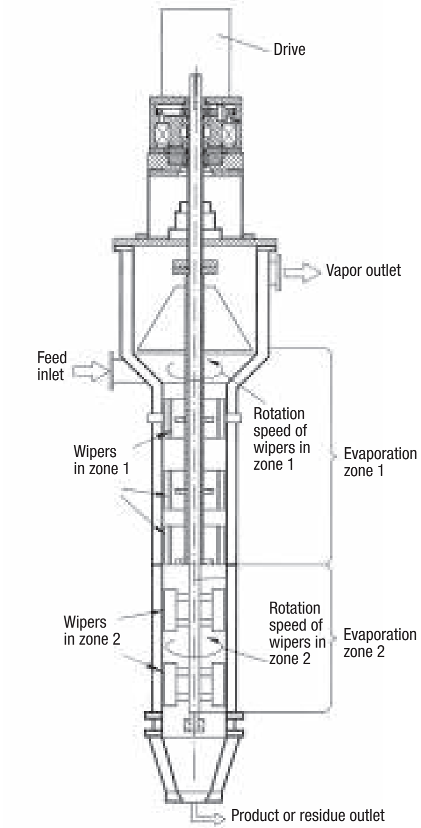


FIGURE 4. This patented design has two evaporation zones that can be heated separately. A coaxial rotor makes it possible to operate the wipers in the two zones at different speeds

The required evaporator size for a given application can be roughly estimated because the *U*-value is mainly determined by λ_W/s_W. Mean values for λ_L and η_L are generally used on the product side.

Simulation

A more precise calculation is possible by using a simulation program. The evaporator is subdivided into many sections, each consisting of a heat exchanger and flash vessel. The flowsheet thus consists of many heat exchangers and flash vessels connected in series. The operating pressure is set at the inlet. The heat duty of each exchanger has to be defined, for example, 10 MJ/h in the upper part of the evaporator and 2 MJ/h in the lower part depending on the task. After having selected the components and estimated flowrate and temperature of the feedstock, the simulation can be run.

After preheating, the more volatile components are removed step by step, whereby the film properties change. The values for λ_L and η_L of each section are used for calculating the local α_L and thus *U*, and the film temperature for estimation of the local ΔT. From this, the area *A* of each section can be determined. The sum of the areas of each section gives the total required wiped film surface area.

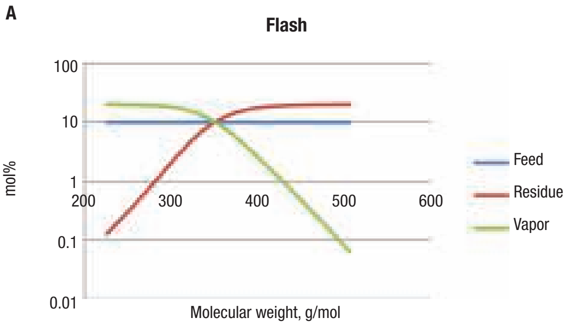
Example 1. As an example, let's consider the overhead distillation of methyl ester containing some glycerol and non-volatile solids, with a feedrate of 130 kg/h. Figure 2A shows the *U*-value as function of the evaporator height (*z*-axis; $z = 0$ at the top of the evaporator). In this example, close to 25% of the evaporation surface of about 0.5 m^2 (according to this calculation) is used for heating of the material and the evaporation of light volatile materials. The *U*-value increases mainly due to the temperature rise of the thin film (decreasing ΔT, see Figure 2B).

Example 2. The second example is the drying of 100 kg/h of an aqueous sludge for which at least – in this case – 1.8 m^2 of evaporator surface might be required. After most of the water has been removed, the material becomes highly viscous and the heat transfer decreases dramatically, as shown in Figure 3A. In practice, the material may not form a film anymore and thereby lose contact to the heated wall so that further drying stops. In a horizontal machine, however, the pre-dried material falls to the bottom hot surface and further drying might be achieved.

Wiping technology

As already stated, the properties of the feed materials can vary a lot: very thin fluids, such as water or ethanol; viscous fluids, such as honey; or doughy materials, sometimes consisting of two phases. Also, the properties of the materials change during the process. The film might become sticky (and form layers), grainy or powdery. To cope with these varying properties, different wiping systems are commercially available.

For drying, the best performances can be achieved by using two evaporators in series, one ver-



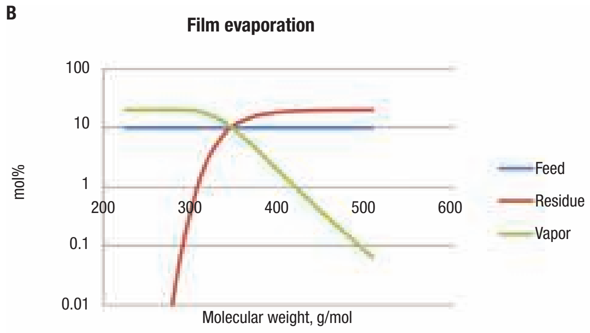
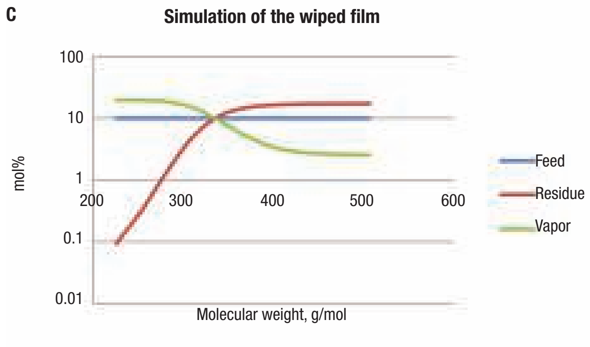


FIGURE 5. These graphs show the simulation results for separation efficiencies of paraffin as used in the cosmetic industry. A better separation efficiency is observed for the wiped-film evaporator (B) when compared to a simple flash evaporator (A). A more detailed simulation of the wiped-film evaporator (see text) shows that more heavy components are vaporized as well (C)



tical and the other horizontal, each equipped with an appropriate wiper system. But to minimize investment and operating costs, users prefer to use only one evaporator. The chosen wiper becomes a compromise. The rotor can be equipped with different wiping elements. Best performances, however, are reached at different circumference speeds. For example, some commercial systems operate with wiper-blade speeds of about 2.5 m/s, and others move at 8 m/s.

The patented design [*3*] shown in Figure 4 has a coaxial rotor. It consists of a hollow shaft rotating at low speed and an inner shaft rotating at high speed. On the hollow shaft are fixed wiping blades, whereas on the inner shaft are fixed pendulums. The two shafts are either driven individually by seperate motors, or, if only one motor is used, by means of a planetary gear.

Separation efficiency

Paraffin wax is used in the cosmetic industry, as well as in packaging and as fuel. For fractionation, wax is usually distilled in a short path still. Let's assume the feedstock consists of 10 components ($C_{16}H_{34}$, $C_{18}H_{38}$, and so on) equally distributed in the feed, each with 10 mol%. The evaporator is run such that half of the molecules are distilled overhead and half remain in the residue. The *U*-value is quite constant because λ_L and η_L do not change much.

Figure 5A shows the distribution of the components in the feed (violet line), in the vapor/distillate (green line) and the residue (red line) as a function of the molecular weight when it is treated in one simple flash with a vapor-to-liquid ratio (V/L) of 0.5.

Figure 5B shows the distribution of the fractions after wiped film/agitated thin-film evaporation. As can be seen, the separation efficiency is sharper. The residue doesn't contain any light molecules.

The thin film might be simulated in more detail by using not only heat exchangers and flash vessels, but by distributing the material partly into the heat exchanger (the portion of material that flows along the evaporator wall), partly in a bypass (the portion that flows in the middle of the film) and partly through the flash vessel (the portion flowing at the film surface). Distributors and mixers have to be included for that purpose and optionally a multi-stream heat exchanger with three sides that is run through by material from the hot wall-heat exchanger on the hot side, by material from the middle section in the middle side and by material that has seen the film surface on the cold side. Heat and mass transfer in the thin film can be analyzed a little better this way.

Of course, such a simulation is somewhat arbitrary, but it shows the direction that the separation efficiency tends toward, in case the feedrate is such that equilibrium is no longer reached. As can be seen from Figure 5C, more heavy components can be vaporized as well.

To verify the layout and design of a wiped film or agitated thin-film evaporator, pilot testing should be performed on the material. ■

Edited by Gerald Ondrey

End note

This topic was first presented at the CHEMCAD User Meeting, which was held in Berlin, Germany on September 16, 2016.

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2. Same as Ref. 1, p. 164
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Dust Management in Bulk-Material-Handling Operations

Dust management can be divided into three main categories: prevention, containment and suppression. Understanding the key considerations for each can help bulk solids handlers arrive at an optimal dust control solution

Mike Lewis
Dust Control Technology Inc.
Mark Strebel
Martin Engineering

Dust management is an ongoing issue faced by virtually every company transporting or processing bulk solid materials, and effective dust control has become an increasingly important challenge in bulk handling applications. Bulk-solids-handling operations are under increased pressure to employ efficient, cost-effective methods of particle control because of a raised awareness of potential dust hazards and tighter regulatory standards.

Depending on the source and ambient conditions, airborne dust can present a number of issues, including potential personnel health and safety hazards, environmental concerns, regulatory challenges and explosion risks, and can contribute to higher equipment maintenance costs and poor community relations. Some of the issues are fairly obvious; for example, dust inhaled by workers or people living in the surrounding community can irritate airways and exacerbate medical conditions, such as asthma. Other issues may not be as obvious. From a purely financial perspective, significant amounts of dust can lead to more frequent maintenance and faster equipment wear, causing operating costs to rise. Fugitive dust can also generate complaints from local residents and businesses, affecting neighbor relationships and potentially creating obstacles to future operating permits. Further, dust and material spillage requires cleaning, which can place staff in the vicinity of moving conveyors and other process equipment, resulting in a higher risk of injury.

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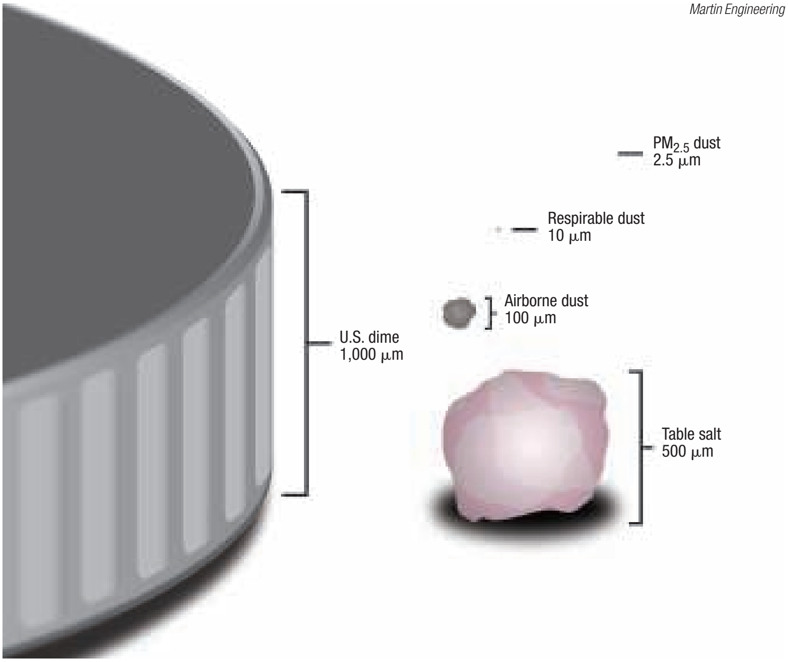

FIGURE 1. The majority of respirable dust particles are too small to see with the unaided eye

Strategies for controlling dust are as varied and numerous as the many different types of solid materials handled in the chemical process industries (CPI). Because of the number and diversity of methods employed to control fugitive particulate matter, material handlers need to do some homework to better understand their individual processes as well as the potential dust-management techniques available to them. Doing so will help operators arrive at the optimum approach for their specific set of conditions. This article describes the three basic categories of dust management — prevention, containment and suppression — and discusses key considerations for each.

Dust defined

In an industrial context, dust is a generic term for small, dry, solid particles ranging from about 1 to 100 µm in diameter. In bulk material handling, these particles are often created in a wide range of sizes, with larger, heavier particles tending to settle out of the air relatively quickly, while smaller, lighter solids may remain airborne for long periods of time. These tiny solids are easily projected into the air by a variety of forces, settling slowly under the influence of gravity. For occupational health purposes, airborne solids are categorized by size as either respirable or inhalable.

The inhalable dust classification is applied to particles that are typically trapped in the nose, throat or upper respiratory tract. The U.S. Environmental Protection Agency (EPA; Washington, D.C.; www.epa.gov) describes this category as particles having a median diameter of about 10 µm. In contrast, respirable dust is small enough to penetrate deep into the lungs, and is usually designated as particles smaller than 10 µm in size. These small particles that migrate deep into the respiratory system are generally beyond the body's natural cleaning mechanisms (such as cilia and mucous membranes) and are likely to be retained. For perspective, a U.S. dime is 1,000 µm thick (Figure 1), so the most potentially hazardous dust particles are the ones too small to see with the unaided eye.

In most bulk-handling applications, primary attention is generally focused on dust particles smaller than 100 µm (0.004 in.), based on the observation that particles under that size have a tendency to stay aloft once they become airborne.

Dust sources in bulk handling

Virtually any activity that disturbs a bulk material is likely to generate dust. Substances composed primarily of smaller, lighter particles can create huge volumes of airborne material if left uncontrolled. Bulk conveying operations and trucks or railcars dumping loads of raw material often struggle to manage this fugitive material. And any activity involving front-end loaders or other heavy loading equipment is almost certain to release airborne particles (Figure 2).

Because they move large amounts of material at high speeds — frequently over long distances — conveyors can be a particularly complex source of fugitive material. Transfer points, for example, are typically composed of drop chutes, impact points and conveyor enclosures, all of which are potential dust sources unless properly designed, installed and sealed. In fact, with the larger, faster conveyor systems currently in use, virtually the entire belt path can be a contributor to the release of dust.

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FIGURE 2. Loading and unloading points for solids can present significant dust control challenges

Contain, prevent or suppress?

Dust management in bulk-handling operations is complicated by the significant number of variables involved — some of which are constantly altered by changes in environment and materials. Dust conditions and methods of control are affected by process designs and plant layouts, production techniques and technologies, dust-control equipment types and system options, and by differences in conveyor design and construction. These changing dust conditions may even be detected on a daily basis within the same operation, particularly from variations in the weather or in the properties of the bulk material. As a result, any recommendations must be made in light of the specific circumstances facing each individual operation. The

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FIGURE 3. Dust containment can be improved by enclosing the settling zone to slow the air velocity and return dust to the cargo flow

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FIGURE 4. Dust bags filter outgoing air to minimize fugitive material, while reducing positive air pressure

first step is to understand the nature of the problem before considering specific options.

When attempting to prevent or control dust, particle shape, size and weight, as well as airflow, are all important factors. The objective is to reduce the velocity of the air and increase the mass of the particles to prevent them from becoming airborne or to assist them in settling out of the air quickly (Figure 3). Dust management efforts generally rely on one or more approaches, with many operations using a combination of methods to achieve maximum effectiveness. The three main strategies are the following: contain the material and reduce, eliminate or control the air to let the dust settle out; prevent the particles from becoming airborne by increasing their mass; or collect, clean or suppress the airborne dust from the air.

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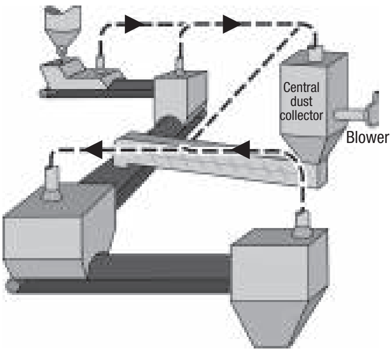

FIGURE 5. Central dust collectors use blowers to create negative air pressure

Material containment

In discussing containment, it is important to keep the material on the belt or within the material stream and to eliminate the creation of airflow, or to confine any air that is created during the material-transfer process. Containment is the foundation of most good dust-control programs and should be the first option considered. The goal is to keep the particles within the flow and prevent wind-aided dust from becoming fugitive material that requires cleanup and presents a potential hazard. Containment is the foundation that should be established as a basis for dustcontrol. This foundation is mechanical in nature and typically has fewer recurring expenses than other options.

Minimizing the drop height of the material should be considered in the design stage of the conveyor system, as this will create a less turbulent transition. If drop height is not effectively managed with the initial build, then properly designed spoons, deflector plates and possibly rock boxes should be considered to reduce the distance that the materials fall and reduce their impact on the receiving belt. The impact of the fall of the material can be handled by the cushioning effect of impact idlers or impact beds. Impact beds improve control over the material by flattening the impact zone of the conveyor. Slider beds continue the process of

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FIGURE 6. Integrated air cleaners are smaller, independently operating units at each dust-generation point

flattening the belt through the settling zone and should be installed after the impact bed(s). Intermittent idlers placed between the beds will reduce friction and heat buildup.

Having established a flat belt line, chute walls with external wear liners should be installed. Placing these wear liners down close to the belt will ensure that the load remains on the conveyor. An external wear liner is located on the outside of the chute for installing and servicing without confined-space entry, and is considered a sacrificial material designed to withstand abrasive cargo. Skirt seals (also known as apron seals) are installed along the belt edge in order to confine air and small particles to the transfer point enclosure. Existing apron-seal technologies deliver reliable and long-lasting sealing performance under most conditions. Innovative designs delivering two wear surfaces on a single elastomer sealing strip allow the seal to be inverted when the bottom side of the strip that rides on the belt is worn, providing a second service life.

For extremely abrasive materials or high belt speeds, engineers have developed new skirt-seal designs to further extend performance and durability. One such innovation is a system engineered with thick elastomer sealing strips. Standard 2-in. (50 mm) or massive 3-in. (75 mm) thick construction featuring innovative swing arms enables its use on reversing belts. This type of system rides gently on the belt, self-adjusting to maintain effective sealing, even as the belt path fluctuates and the sealing strip wears. A range of elastomer formulations are available to suit specific application needs.

Controlling airflow

Several of the process improvements that provide material containment also assist in minimizing or controlling the air within the transfer point. Changes in system design — such as transfer point redesign — or in-production techniques that will reduce the amount of fugitive dust produced should be considered.

Minimizing the height difference between the loading and receiving conveyors helps control the material, but it provides even greater advantages in minimizing airflow. Transferred material spreads out when it leaves a head pulley and pulls air into the flow as it travels. When the material reaches its destination, this energy is released at impact. The air picks up particles and drives dust toward the path of least resistance and out into the atmosphere. In general, transfers should avoid drastic changes in material speed or trajectory, maintaining a cohesive material stream while controlling the flow of air entering and exiting the transfer point.

Flow chutes. Engineered flow chutes accomplish this by loading material in the same direction and speed as the receiving belt and confining the material stream, minimizing any disturbance in the material flow. The hood, located at the discharge of the loading conveyor, minimizes the expansion of the material and deflects the stream downward. The spoon, located at the entry of the receiving conveyor, provides a curved loading chute that delivers a smooth transfer in order to allow the material to slide down to the receiving conveyor or vessel. These chutes are designed to feed the material

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FIGURE 7. The most common and least expensive dust-prevention technique is moisture addition

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FIGURE 8. Customizable dust control systems are available from some suppliers to deliver application-specific components

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FIGURE 9. Dust suppression involves preventing dust particles from leaving the material stream

evenly, controlling the speed, direction and impact of the material in the load zone. As a result of the tighter stream, less air is entrained in the system and thus less air is discharged, picking up less dust for potential escape. Engineered chutes normally require large capital investments, and care must be taken to account for changes in the amount and speed of the material handled, along with changes in characteristics, such as moisture, as these can lead to excessive chute wear, plugging or other issues.

Containment. For effective airflow control, a good containment design with an effective dust-settling zone is critical, since it forms the basis for air control with a belt that has been flattened and sealed to prevent material and air from escaping. Impact beds and slider beds flatten the belt, while chute walls, wear liners and apron seals keep the material on the belt. In order to address the air that has been created in the transfer process, the enclosed chute should be turned into a settling zone of sufficient dimensions, such that all material is kept on the belt, including any dust that was created in the process.

Allowing the air to slow and the dust to settle requires an enclosure large enough for the air to expand and lose velocity. As air velocity drops, airborne particles can no longer be kept suspended by the airflow present, and the particles begin settling out of the air stream and back into the cargo flow. The height and width of the settling zone are critical in increasing the area and should be designed as wide and as high as necessary to decrease the air velocity to less than 200 ft/s to minimize any dust pickup. The length of the zone should be considered in order to allow time for the settling process to take effect.

To improve the effectiveness of the settling zone and reduce the size required, the amount of air entering the transfer should be minimized by sealing the conveyor entry. To improve the effectiveness of the zone, a curtain can also be installed near the exit to provide resistance to the airflow leaving the enclosure. Narrower curtains added intermittently within the stilling zone can create a circuitous path for the air to follow, assisting with the particle-removal process.

In a properly-engineered transfer, each component — from the chute to the impact cradles, idlers and seals — is employed to maximize its specific function and contain dust and fines, while at the same time offering workers easy access for maintenance. The whole system should work efficiently, retaining the maximum amount of cargo at the highest achievable volume, while still offering the safest work environment possible.

Due to space or structural considerations, it's sometimes necessary to provide a further assist in reducing air velocities. This can be provided by an air-removal device. After effectively containing the air, excess air can be relieved with the dust retained in the material flow utilizing

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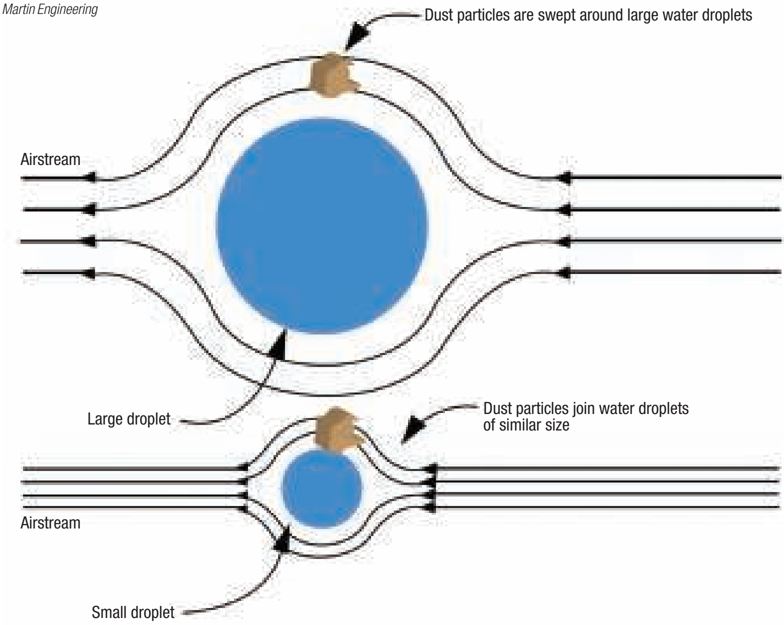

FIGURE 10. A slipstream is created when water droplets move swiftly through the air. The size of the droplet determines whether or not it will interact with dust particles

various methods. One approach is the installation of one or more dust collector filter bags.

Dust collectors. Dust bags provide a method of relieving positive air pressure within the system, while also filtering the dust and minimizing its escape (Figure 4). Often attached with a simple circular clamp to the rim of a port in the enclosure, the dust is captured inside, creating a filter cake. A large transfer point may require more than one bag, depending on the size and permeability of the bag and the airflow at the transfer point. Dust bags usually feature a grommet at the top, allowing them to be hung from overhead supports. They are generally designed to collapse when the conveyor is not running, allowing filtered material to drop back onto the belt. Care should be taken to avoid getting dust bags wet, because moisture will affect performance.

In most cases, no single component will deliver adequate particle control, but when used in concert, these technologies provide significant improvements in dust management. The techniques discussed so far are considered passive dust control. When necessary, air cleaning systems (active control) can also be used to filter the air and trap airborne particles.

Air cleaners. One common air-cleaning system design is the central dust collector (Figure 5). Installed in a central location and connected to the individual collection points by means of sealed ductwork, this type of filtration system would handle the dust extracted from the entire conveying system, collecting it for disposal or feeding it back into the process. Due to their large size and various permitting limitations, these units typically are required to meet very specific design and location criteria.

Central collectors utilize a blower to produce negative pressure inside the system, drawing air through the filter media where dust is deposited and a filter cake is created. The blower is sized to manage the required airflow, while overcoming losses due to pressure drop across the system, including pressure losses in the ducts between the collector and the pickup points. Ducting used to connect the collector to the pickup point must be designed and configured to prevent dust from settling out of the air stream at any point along its path to the collector.

Although widely used in the past, central dust collection systems have several undesirable attributes, including the following:

- Build-up of material in the ducts causes operational and safety concerns
- Potential explosion hazards from accumulated combustible material
- Large capital investments and high power usage
- Challenging maintenance issues, such as system-wide airflow balancing

Collected dust is often recirculated back to the conveyor from which it came, and this practice can involve a material drop, which then creates airflow and dusting issues.

FIGURE 11. Atomized mist is one of the few techniques able to control both surface dust and airborne particulate matter

Otherwise, the material collected by the central collector requires some method of disposal, increasing operating costs.

A better alternative to central collection for many operations is the integrated air cleaner, designed to individually collect dust at the source by employing a series of smaller, independently operating units (Figure 6). Unlike central systems, particles are not stored. The blower pulls dust-laden air through the filter, where particles are deposited on the filter media. Each particle is pulled into other particles already on the filter, where they agglomerate into a filter cake. This cake of larger, heavier agglomerated particles is periodically discharged back into the material stream.

These compact units need only to contain the blower and the required filter media, and are designed to be placed on top of (or close to) the conveyor system or other pickup point where dust control is desired. These integrated systems do not need to be located outside, as they do not store dust.

Integrated units pull air from the settling zone with a blower sized to remove the excess air from the enclosure. No ducting means less pressure drop, reducing overall power requirements and operating costs. These integrated air-cleaner designs feature a pulse-cleaning system, which uses a short burst of air sent back through the filter to dislodge accumulated solid material. Filter changes are a no-tool procedure from the clean side of the dust collector. These cleaners are easy to install and maintain, eliminating many of the issues experienced when using central collection systems.

Controlling particle size

Air cleaning devices deliver mechanical agglomeration of dust particles into heavier particles. Another method utilized to increase the mass of dust particles is to add moisture. Moisture addition increases the weight and cohesiveness of particles, thereby creating larger, heavier particles that are prevented from ever becoming dust (Figure 7).

Water addition. Water is the most common and least expensive process additive to prevent dust. It can be added in numerous ways, but a critical question is this: how much moisture can the material tolerate?

Unfortunately, there's no universal answer. Every process, every material, even different loads of the same material, can exhibit different characteristics. Adding a known percentage of moisture may be an effective solution at a given site, while a relatively minor fluctuation could result in significant changes in physical properties, leading to thermal penalties, plugged chutes or quality loss.

The one property solid materials have in common is a minimum and maximum moisture content for dust prevention. Experienced material-handling-equipment manufacturers often have sophisticated testing facilities to investigate the physical properties of a material, allowing them to determine optimum moisture-addition levels for typical materials.

Many suppliers offer spray bars and other components aimed at large-scale saturation. These are normally simple systems with little if any control, aimed at flooding the material in order to keep the dust down. At times these systems are updated to provide some customizable control in an effort to minimize saturation. Often, these plain water systems are not sufficient to effectively control the dust.

In addition, many materials have a tendency to repel plain water or combine poorly with it. This often leads to excess moisture being added to the process, creating a mess in the plant and increasing the costs associated with handling and cleaning up the material. This excess moisture leads to additional material carryback, plugged chutes, belt tracking problems and housekeeping issues.

Dust-control formulations. In order to regulate the moisture addition required to control the dust, chemical formulations have been engineered to provide optimum results. Many of these dust-control products offer some combination of wetting agents, binding agents or crusting agents to improve performance. These additives improve the ability of the water droplet to combine with material particles, thus increasing the mass of the particles. Dust-control additives increase particle cohesiveness in order to get the particles to combine more readily, improve the longevity of those bonds, and create a seal that enhances the long-term effects of the product.

The individual characteristics of each application present specific needs that can be met through a combination of commercially available surfactants and tackifiers. The right match of additives and application delivers effective control for the material handling circuit. Many applications can handle several transfers, while preventing dust from being created during stack-out and storage.

Spray techniques. These products can usually be applied as a spray or as a foam. Proper application enhances their effectiveness by ensuring that they contact as much of the bulk material as possible. Top-coating is a common practice and is often less effective than alternate application methods. If top-coating is used, care should be taken to ensure that the product applied stays on the material, rather than on the belt or the chutes. Overspray or unabsorbed product is a waste.

Systems that apply water with dust-control additives as a spray should be applied as the material leaves the head pulley for maximum effectiveness, because at that point, the solid material has spread out and is most ready to receive the moisture. By applying the suppressing agent with some force to the spray and in several locations around the material stream, the suppressing agent is able to penetrate into the material and provide a good coating. Recent improvements in dust control technology have enabled applicators to apply effective wet-spray control at lower moisture-addition rates than in the past.

Systems applying water with dust-control additives as a foam utilize additional chemistry and apply air to the product in order to create the foam solution, which can increase the costs of operating a dust-control system and should be considered in the evaluation. Foam is applied to the material with less pressure and depends on the turbulence of the system for effective mixing.

Turnkey suppression systems are available from some manufacturers to meet user needs. Some are designed with modular elements configured to best suit the specific operating conditions and requirements of the individual operation. An effective system should be capable of sensing material movement and controlling system operation accordingly. Water and dust-control product should both be applied with variable flow in order to maintain chemical-to-water ratios, while providing for independent control at multiple application points. These systems should provide fail-safe mechanisms in order to protect operations from liquid spills or equipment damage due to system faults.

New customizable wet-spray application systems have become available in the marketplace that are simple to install and provide versatility not typically found in stock suppression methods (Figures 8 and 9). These systems, combined with other dust-management methodologies, provide users with a wide range of dust-control and containment options for improved effectiveness and efficiency.

Foam-application systems are typically a more expensive design and may offer fewer options, because compressed air is required. Foam systems are typically more maintenance-intensive, as they require specific water, foaming agent and air combinations to create good foam. Changes in the system needs or air and water supplies require system adjustments.

Dust suppression

In operations where containment is impossible and the creation of dust is not preventable, suppression may be an option. Suppression involves treating the dust particles once

FIGURE 12. This atomized mist design employs a 60-hp fan and a high-pressure booster pump

they have been released from the bulk material stream, typically using plain water or an aqueous solution. Airborne droplets combine with the dust particles, making them heavier so they fall out of the air stream. These systems normally apply water as a fog or atomized mist. Fog is a light mist and therefore susceptible to air currents. Successful application of a fog system requires an almost windless location, such as an enclosed stilling zone of a conveyor, in order to be effective.

Some operations may use hoses or industrial-sized sprinklers on outdoor applications, which can be effective at immobilizing ground-level particles. Unfortunately, these options usually require large volumes of water, which can create additional complications, such as runoff. Aside from the cost of the water, hoses and sprinklers are also fairly localized methods, requiring repositioning or manual spraying.

Their greatest drawback, however, is droplet size: water droplets produced from hoses and sprinklers are simply far too large to have any meaningful effect on airborne dust particles. The size of the droplet is important: hoses and large sprinklers common to large bulk-handling operations typically produce water droplets between 200 and 10,000 μm in size, which are large enough to create a phenomenon known as the “slipstream effect” (Figure 10).

A slipstream is created when a mass moves swiftly through the air. Like the air moving around an airplane wing and keeping the craft aloft, a slipstream also travels around a large falling water droplet. Smaller dust particles can get caught in this slipstream and get directed away from the droplet, so that the particle remains airborne. Very small water droplets produce virtually no slipstream and linger in the air much longer, increasing the chance of a collision with an airborne dust particle.

For this reason, a more effective option for large open areas is an atomized spray, which relies on the principle of creating tiny droplets of a specific size range and delivering them at relatively high velocity over a wide coverage area, inducing collisions with dust particles and driving them to the ground.

For large open areas, such as storage piles, crushing operations and loading/unloading stations, basic spraying techniques such as sprinklers or hand-held hoses have a tendency to saturate target surfaces, often resulting in excess water that can damage sensitive cargo. The range of these techniques also tends to be quite limited, frequently requiring significant staff time to handle the hoses or reposition sprinkler heads. In contrast, atomized mist has proven to be one of the few technologies capable of delivering dust control via airborne capture and surface wetting.

Because all of the elements in atomized-mist dust-control equipment tend to have an effect on each other, each component must be designed to achieve an optimum balance, including the pump, nozzles, barrel and fan. Changing any of these elements can have consequences for droplet size, velocity, spray angle, pattern and range. All of these elements must work together for maximum efficiency.

In large operations or facilities that store significant amounts of material outdoors, atomized mist technology delivers highly effective suppression over large open areas, with some equipment capable of covering as much as 280,000 ft^2 (26,000 m^2) — nearly six football fields — with a single machine (Figure 11).

Some manufacturers have even developed turnkey systems that include a diesel generator and electric-powered atomized misting unit mounted together on a roadworthy trailer (Figure 12). Designed for large open-air applications, these systems deliver effective particle control in a highly-mobile platform that can be positioned directly at the source of dust-generating activities. With a range of up to 100 m, they can deliver effective particle management at remote sites without an available power supply. Some of these new designs can even be specified with a high-lift pump for drawing water from a stationary source, such as a private pond.

Unlike industrial sprinkler systems used for dust management, which can require as much as 500 gal/min (1,893 L/min) of water, even large atomized mist equipment typically uses less than 40 gal/min (151.4 L/min) to help avoid pooling or runoff. Many of these can also be outfitted with a dosing pump to accurately meter in surfactants or tackifiers to further enhance binding of dust particles. Standard designs are typically engineered to use a potable water source, but many can also be outfitted with a selection of filters to handle non-potable water. For applications in which the water contains high amounts of sediment, additional external filters can be used.

While some atomized-mist designs are engineered to run directly from diesel engines as their power source, experience has shown that an electric motor delivers quieter and more durable performance. Maintenance requirements for the electric units are typically minimal, and some suppliers provide a 3-yr, 3,000-h warranty.

Of particular interest in certain applications is the evolution of atomized mist technology for odor control. With the development of specialized vaporizing nozzles, these systems can create an engineered fog comprising millions of tiny chemically enhanced droplets as small as 15 µm in diameter (approximately twice the size of a human red blood cell).

Delivered by a special open-ended barrel design containing a powerful fan, these devices can also be mounted on a towable roadworthy trailer fitted with a dedicated water tank that gets filled with a pre-mixed solution of water and highly-effective odor-treatment chemical. The water content of the solution quickly evaporates once dispersed into the air, leaving behind the deodorizing vapor, which can hang suspended for long periods of time as the microscopic droplets attract and counteract odor-causing molecules. The devices can be used for active odor control spread over wide areas, as well as topical treatment or a perimeter barrier.

Concluding remarks

No two bulk solid materials are the same, no matter what type or classification they fall into. Similarly, every conveying system will have its own individual characteristics. It is important for users to examine the features, construction and trouble points of their systems as unique entities, without making assumptions that could lead to unsatisfactory results.

Dust management should be viewed as a process, and as an integral part of the material-handling system, optimized to prevent dust from being developed whenever possible by doing one or more of the following:

- Applying containment in the right places
- Applying moisture to the product to improve agglomeration
- Utilizing air cleaners when moisture is not an option or excess air is present
- Dealing with trouble spots where point source application is not practical
- Employing open air suppression technology where needed

If an existing material-handling system successfully manages dust and spillage upon installation, it should continue to work as long as the material stays the same and the equipment does not suffer wear or abuse that alters its performance. Keep in mind that major changes in material (such as a new source or increased moisture), or alterations in the process or equipment (such as increasing belt speed to move more material), can have dramatic consequences on the dust management of a bulk handling system. Even minor changes in material (such as a change in the atmospheric humidity) can impact the performance of a material handling system. ■

Edited by Scott Jenkins

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Considering Fugitive Emissions During the Conceptual Design Stage

The ability to reduce fugitive emissions through the use of strategic design modifications not only protects workers and the environment, but reduces losses of valuable process materials

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The industrialized nations of the world have all placed increased emphasis on the control of industrial emissions, to protect the atmosphere. Many types of emissions result from process streams, and as such, can be controlled by operators with the right engineering interventions. However, a considerable proportion of emissions are unanticipated fugitive emissions [*1*]. Fugitive emissions are defined as a chemical, or a mixture of chemicals, in any physical form, released as a result of an unanticipated or spurious leak in an industrial site [*2,3,4*]. Such leaks occur because of discontinuities in the solid barrier that is intended to maintain containment.

Worldwide, fugitive emissions from industrial applications amount to more than a million metric tons per year (m.t./yr), and fugitive emissions in the U.S. are estimated to be in excess of 300,000 m.t./yr, accounting for about one third of the total organic emissions from chemical plants [*5*]. This situation is mirrored in Europe, and is likely worse in other parts of the world, where emission standards and policing levels may be lower.

Fugitive emissions create not only environmental and health issues, but they have economic impacts, as well. Fugitive emissions represent a loss of potentially valuable materials and reduce overall plant efficiency [*6*]. In many cases, the true economic impacts are not recognized, because many of the costs associated with fugitive emissions are not readily apparent. Since October 2007, all existing processing plants and power stations within the European Union (E.U.) have had to comply with the IPPC directive 96/61/EU, which aims to improve the management of industrial processes and ensure a higher level of protection for the environment. The challenging environmental, health and economic demands that are driving the need to reduce leaks and fugitive emissions [*7*] are more urgent than ever. The implementation of legislation in the U.S. governing emissions of volatile organic compounds, together with E.U. directives, has provided a stimulus for work aimed at reducing fugitive emissions.

TABLE 1. STREAM CONDITION FOR IPA-WATER SEPARATION EXAMPLE

Stream	*S*	*F*	*D1*	*B1*	*D2*	*B2*
Phase	Liquid	Liquid	Liquid	Liquid	Liquid	Liquid
T, °C	75	75	82	169.4	100.1	209.1
P, bar	2	2	1.01	1.95	1.01	1.43
Mass composition, wt.%						
EG	100.00	0.00	0.00	92.82	1.61	100.00
Water	0.00	13.90	0.16	7.18	98.39	0.00
IPA	0.00	86.10	99.84	0.00	0.00	0.00

Conceptual design and FEED

This article focuses on how fugitive emissions should be considered during the conceptual design and front-end engineering design (FEED) stages. As shown in the example in this article, an emission factor is applied to estimate the amount of potential fugitive emissions that could be expected, as well as the potential atmospheric concentration and associated health risks. The health risk is then calculated using the established Health Quotient (HQ) Index, a dimensionless value that indicates a relative health risk between two or more processes or scenarios based on the amount of fugitive emissions generated by both (HQ is typically expressed as a ratio of emission concentration and exposure limit).

The example discussed in this article demonstrates the estimation of potential fugitive emissions from an extractive distillation system that consists of two distillation units. The process involves the extraction of isopropanol (IPA) from water using ethylene glycol as the entrainer (the entrainer is the solvent used in an extractive distillation system). Since actual plant monitoring data were not available, an estimation method was used, based on the Average Emission Factor approach discussed in Ref. 8.

The fugitive emissions rate obtained using that methodoogy was then used as the input data to determine the resulting chemical concentration (based on the volumetric flowrate of air) within the process area. In this estimation exercise, the volumetric flowrate is estimated,

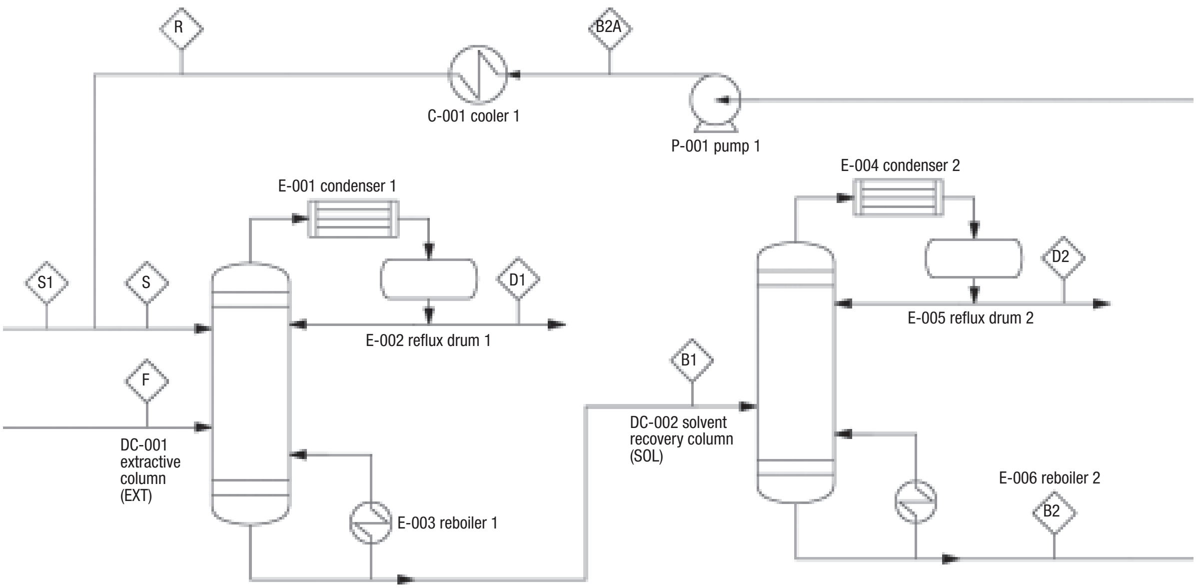

FIGURE 1. This diagram shows the PFD of an extractive distillation system for IPA-water separation. This system provides the basis for the estimation methodology discussed in this article

since the process is still in the design phase. This calculation requires data on wind speeds, plot dimensions and the maximum height of the column or vessel below which the leak sources reside [*9–11*]. The details on how the calculations are performed are described below.

The example discussed here examines the estimation of a chemical concentration that could result from fugitive emissions for both the process flow diagram (PFD) and the piping and instrumentation diagrams (P&ID), both of which are important diagrams used during the conceptual design and FEED stages, respectively. Note that one may further differentiate the calculation using preliminary PFD and detailed PFD, with the latter having results of mass and energy balances [*9*]. Only the latter one (that is, with detailed mass and energy balances available) is considered in this article.

The estimated values calculated using the methodology described here serve as input data for estimating the associated health risk for the proposed design at any stage. Such risk estimation is vital in predicting the potential adverse health impacts workers could encounter, due to potential fugitive emissions released from the proposed process or plant design.

Illustrative example

The PFD of extractive distillation for the separation of IPA and watercon- sists of two distillation columns with a direct sequence (Figure 1). In the extractive column (EXT), ethylene glycol (EG), which is used as the entrainer (Stream S), is introduced at the stage above the azeotropic feed. This design allows for enhanced contact with the binary mixture, which facilitates separation. Stream F consists of a fresh feed of the binary mixture (65% IPA and 35% water).

The entrainer EG changes the relative volatility of the chemicals and directs IPA to the distillate stream of the EXT column. At the same time, water and EG leave in the column bottom stream, and are fed to the solvent-recovery column (SOL). In the latter, the heavy entrainer EG will be separated from water by a binary distillation and the EG is recycled to the EXT column. The stream conditions (temperature, pressure and mass compositions) are shown inTable 1.

Calculation for the PFD level

The potential fugitive emissions (FE) rate for the PFD level is calculated based on the pre-calculated module data, as shown in Table 2. These data were originally reported by Hassim and others [*9*] to assist designers in performing emissions estimation from their process. Despite this apparent simplification, these data are reliable since the emissions values in the database were calculated based on the actual P&ID of the typical process modules (unit operations) in chemical plants. Note that there are useful data for other reported unit operations, such as columns, reactors and more. Readers may refer to the original source [*9*] for these data.

As shown in Table 2, in order to estimate fugitive emissions, the service type of the streams must be identified. For liquid streams, the stream service type is classified according to their vapor pressure and mass compositions. To be classified as light liquid (LL), the vapor pressure of the pure component at 20°C needs to be higher than 0.3 kPa (vapor pressure for the three pure components, in the example is

TABLE 2. FUGITIVE EMISSION RATES FOR NORMAL DISTILLATION COLUMN, EXTRACTED WITH PERMISSION (REF. 9)

Stream	Service*	FE_i, kg/h
Feed 1	LL	0.036
	HL	0.021
Outlet 2/3	LL	0.405
Outlet 3/4	HL	0.021

LL= Light liquid
HL= Heavy liquid

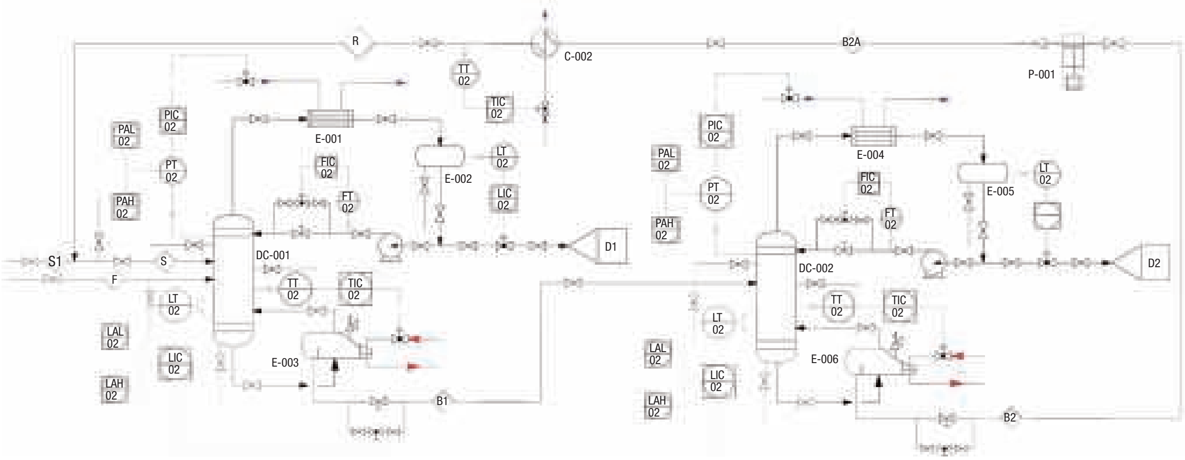

FIGURE 2. Here is the P&ID for the extractive distillation system used for IPA-water separation, which is discussed in the case example profiled here

given in Table 3). For a liquid stream with mixture of chemicals (which is very common in the chemical process industries), the summation of these components should be ≥20 wt.% in the stream mass composition. Otherwise, the liquid stream is regarded as heavy liquid (HL). As for gas streams, the classification is much more straightforward, as it is regarded directly as gas service.

The values in the database yield the amount of potential fugitive emissions from that particular process stream. Because the process stream is comprised of a mixture of chemicals, the stream emissions rate is multiplied by mass composition of each chemical component, to obtain the amount of potential fugitive emissions of the individual components, respectively; results of this calculation for the case example discussed here are shown in Table 4.

For example, the feed stream of the extractive column (Stream F) consists of 13.9% of water and 86.1% of IPA. Since its LL weight is higher than 20 wt.%, the estimated fugitive emission of the stream is reported as 0.036 kg/h, according to Table 2. This estimated stream value is assumed to be contributed by water and IPA according to their mass composition, that is, 0.005 kg/h (=0.036 × 13.9%) and 0.031 kg/h (=0.036 × 86.1%), respectively. The total amount of fugitive emission for the respective component is then determined by summing up the emisEGsion rates of this particular chemical component in all process streams throughout the process, given in the last three rows in Table 4.

Calculation for the P&ID level

The P&ID is an important diagram used during the FEED stage of plant design. By taking the P&ID into consideration, we can estimate fugitive emissions in a more accurate and wide-ranging manner because the diagram provides more details about the process. At this stage, the actual piping and connections are made available, therefore enabling more precise data estimation.

As shown in the P&ID diagram for the IPA/water separation in Figure 2, identification of all potential leak sources (flanges, relief valves, valves, pumps, sampling points, and heat exchanger heads) are calculated using the guidelines provided in Table 5.

As shown in the database (Table 5), the emissions rate is now more equipment-specific. At this stage, all piping and instrumentation have been identified and more accurate emission factors are used to estimate the fugitive emission caused by the extractive distillation system. Note that data for other equipment, such as compressors, rotary, bolted manways and hatches were also reported by Hassim and others in Ref. 7.

The number of piping equipment components is first identified and summed to obtain an appropriate emission factor, as shown in Table

TABLE 3. ATMOSPHERIC VAPOR PRESSURE AT 20°C	
Component	Vapor pressure
EG	0.0075 kPa
Water	2.4 kPa
IPA	6.02 kPa

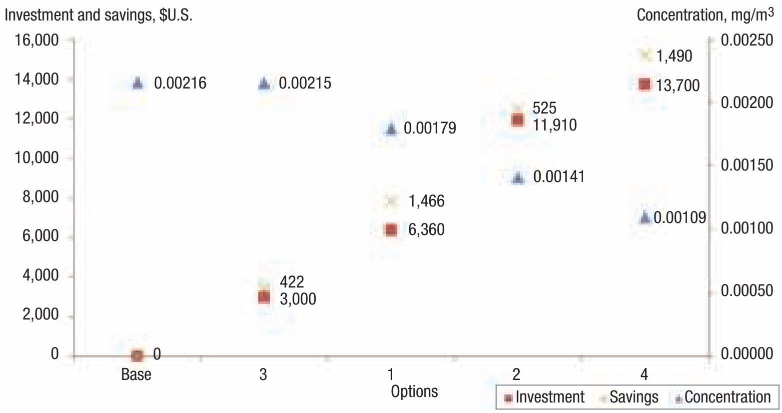

FIGURE 3. This impact diagram shows the savings, investment and reduction in emissions concentrations for the various options (listed in Table 13), allowing engineers to assess their options

TABLE 4. FUGITIVE EMISSION CALCULATION FOR THE PFD LEVEL						
Process unit	**Standard module**		**Fugitive emission**			
Extraction	Distillation column	Streams	*S*	*F*	*D1*	*B1* (Outlet)
		LL weight	< 20 wt.%	≥ 20 wt.%	≥ 20 wt.%	< 20 wt.%
		Service	HL	LL	LL	HL
		FE_i, kg/h	0.021	0.036	0.405	0.137
		EG, kg/h	0.021	0.000	0.000	0.127
		Water, kg/h	0.000	0.005	0.001	0.010
		IPA, kg/h	0.000	0.031	0.404	0.000
Separator	Distillation column	Streams	*B1* (Inlet)	*D2*	*B2*	
		LL Weight	< 20 wt.%	≥ 20 wt.%	< 20 wt.%	
		Service	HL	LL	HL	
		FE_i, kg/h	0.021	0.405	0.137	
		EG, kg/h	0.019	0.007	0.137	
		Water, kg/h	0.002	0.398	0.000	
		IPA, kg/h	0.000	0.000	0.000	
TOTAL	EG		0.311 kg/h (86.44 mg/s)			
	Water		0.401 kg/h (112.50 mg/s)			
	IPA		0.435 kg/h (122.50 mg/s)			

6. Similarly, the emissions rate for each process stream is determined based on the respective component mass composition, as shown in Table 7. Similar to the PFD case, the total emission rate for the respective components is estimated by summing the respective emission rates in the individual streams.

Estimation of health risk

The section above allows us to determine the fugitive emission rate at different stages of design. However, the HQ is determined based on chemical concentration. Therefore, estimation of volumetric flowrate based on wind speed and process module area is required to obtain the emitted chemical concentration. The relationship between emission rate and concentration is given by Equation (1):

$$C_i = \frac{FE_i}{\dot{V}} \quad (1)$$

Where:
C_i = The concentration of chemical *i*, mg/m^3
FE_i =The emission rate of chemical *i*, mg/s
$\dot{V}$ = The air volumetric flowrate, m^3/s, which is calculated based on Equation (2):

$$\dot{V} = vA_n \quad (2)$$

Where:
v = wind speed, m/s
A_n = process module area, m^2

As indicated by Equation (2), the area of the process modules is needed in order to determine the air volumetric flowrate. Note that there are differences when estimations are done based on the PFD and the P&ID. The latter takes wind direction into account, as the real plot plan is available, resulting in a more accurate estimation of the cross-sectional area.

On the other hand, values derived at the PFD level are based on the average floor area, average wind speed and average height of piping components. For the simple example that involved only two distillation columns, estimation of airflow based on the PFD is adequate.

Table 8 shows a reported average floor area for some common modules in the chemical process plants [9]. Readers may also refer to the original source for data of other process module, such as flash column, stripper, compressor and so on. The average floor area for the IPA/water separation example is hence calculated based on the reported value for the distillation module (that is, 129 m^2, as shown in Table 9). The main assumption made is that the plot plan is a square shape (to obtain the edge width area), while the process vertical area is calculated using an average piping height of 7 m.

As the emission rate for respective chemicals in the process stream has

TABLE 5. FUGITIVE EMISSION RATES FOR EQUIPMENT AND PIPING ITEMS FOR THE P&ID LEVEL, EXTRACTED WITH PERMISSION FROM REF. 9		
Equipment	**Piping components**	**FE_i, mg/s**
Valve stem	Rising valve	1.7
Flange	Flanges	0.056
Pump shaft seals	Pump (Single mechanical seal)	1.7
Pressure-relief valve	Pressure-relief valve	2.8
Heat exchanger	Heat exchanger head	0.111
	Sampling point	4.17

TABLE 6. NUMBER OF EQUIPMENT AVAILABLE IN EACH PROCESS STREAM

Process unit	Standard module	Piping components	FE_i, mg/s	Stream classification			
Extraction	Distillation column (Extractive column)			*S*	*F*	*D1*	*B1* (Outlet)
		Rising valve	1.7	2	1	9	3
		Flanges	0.056	13	6	38	19
		Pump (single mechanical seal)	1.7	0	0	1	0
		Pressure-relief valve)	2.8	0	0	1	1
		Heat exchanger head	0.111	0	0	2	2
				Feed	Top	Middle	Reflux drum
		Sampling point	4.17	2	1	1	1
Separation	Distillation column (Solvent-recovery column)			*B1* (Inlet)	*D2*	*B2 - R*	
		Rising valve	1.7	1	9	3	
		Flanges	0.056	6	38	32	
		Pump (Single mechanical seal)	1.7	0	1	1	
		Pressure-relief valve	2.8	0	1	1	
		Heat exchanger head	0.111	2	2	4	
				Feed	Top	Middle	Reflux Drum
		Sampling point	4.17	1	1	1	1

TABLE 7. FUGITIVE EMISSION CALCULATION FOR THE P&ID LEVEL

Process unit	Standard module		Stream classification			
Extraction	Distillation column	FE, kg/h	*S*	*F*	*D1*	*B1* (Outlet)
			0.0448848	0.0223416	0.094752	0.0380016
		EG, wt.%	100.00	0.00	0.00	92.82
		EG, kg/h	0.045	0.000	0.000	0.035
		Water, wt.%	0.00	13.90	0.16	7.18
		Water, kg/h	0.000	0.003	0.000	0.003
		IPA, wt.%	0.00	86.10	99.84	0.00
		IPA, kg/h	0.000	0.019	0.095	0.000
Separation	Distillation column	FEi, kg/h	*B1* (Inlet)	*D2*	*B2-R*	
			0.0231408	0.084672	0.0726336	
		EG, wt.%	92.82	1.61	100.00	
		EG, kg/h	0.021	0.001	0.073	
		Water, wt.%	7.18	98.39	0.00	
		Water, kg/h	0.002	0.083	0.000	
		IPA, wt.%	0.00	0.00	0.00	
		IPA, kg/h	0.000	0.000	0.000	
Total		EG	0.176 kg/h (48.79 mg/s)			
		Water	0.091 kg/h (25.26 mg/s)			
		IPA	0.114 kg/h (31.62 mg/s)			

been identified in the PFD and P&ID stage, the concentration for each stage can be determined, based on the calculated volumetric flowrate of air. This is shown in Table 10.

As the components involved are classified as non-carcinogens, the method used to estimate the risk of chronic exposure is to calculate the HQ, using an exposure limit based on 8 h. As noted, HQ is typically expressed as a ratio of emission concentration and exposure limit. As the system consists of a mixture of components, the HQ mix is

TABLE 8. AREA FOR PROCESS MODULE TYPE (REF. 9)	
Process module	**Area, m^2**
Distillation (EXT)	129

the summation of the HQ values of the individual components. An HQ value of <1 is widely acceptable, where the associated risk is considered minimal. Results (Table 11) show that the extractive distillation system yields HQ values of 0.00397 and 0.00216, for the PFD & P&ID level, respectively. Both values fall well below the acceptable safe range of <1.0, indicating that the system is relatively safe.

Reduction of fugitive emissions

Although it has been identified that this extractive distillation system is relatively safe, additional efforts are still needed to continuously improve the health quality of the process plants. According to material safety and data sheet (MSDS), longterm exposure to IPA and EG can cause targeted organ failure. Process operators should seek methods to further reduce fugitive emissions due to the process operations.

A few improvement strategies are shown in Table 13. For instance:

- Option 1 involves modification of valves (to use those with a higher rating) and also pumps (to favor those with double mechanical seals) in the solvent-recovery column (SOL)
- Option 2 includes replacement of valves (to use those with higher rating) and also pumps (to favor those with double mechanical seals) in both the extractive and recovery column
- Option 3 involves reducing solvent (EG) usage
- Option 4 introduces an online sampling method to reduce the number of sampling points (which is the source of fugitive leakage)

These options were evaluated monetarily, in terms of investment made and savings obtained, as compared to the base case. The investment made takes into account of modification and implementation costs (Table 12). For instance, installing 13 units of valves with a higher rating would cost a total of $4,810 [(270+100) × 13)]. On the other

TABLE 9. PROCESS MODULE AREA AND AIR VOLUMETRIC FLOWRATE DETERMINATION

Process unit	Equivalent standard module	Value
Extraction	Distillation column (EXT)	129 m^2
Separator	Distillation column (SOL)	129 m^2
Total, A_f, m^2		258
Edge width of area, d= $(A_f)^{0.5}$, m		16.06
Process vertical area, A_n = 7d, m^2		112.44
Air volumetric flowrate, m^3/s		449.75

TABLE 10. EMISSION CONCENTRATION BASED ON WIND SPEED OF 4 M/S

Stages	Component	Fugitive emission, mg/s	Air volumetric flowrate, m^3/s	Emission concentration, mg/m^3
PFD	EG	86.44	449.75	0.192
	Water	111.28	449.75	0.247
	IPA	120.93	449.75	0.269
PID	EG	48.79	449.75	0.108
	Water	25.26	449.75	0.056
	IPA	31.62	449.75	0.070

TABLE 11. HQ FOR PFD AND P&ID

Stages	Component	Emission concentration, mg/m^3	Exposure limit, mg/m^3	Risk (HQ)
PFD	EG	0.192	52	0.00370
	IPA	0.269	999	0.00027
			Total	0.00397
P&ID	EG	0.108	52	0.00209
	IPA	0.070	999	0.00007
			Total	0.00216

TABLE 12. COST FOR REPLACEMENT AND IMPLEMENTATION

Component	Cost, $	Estimated implementation cost per unit, $
Double mechanical seal pump[1]	1,300	250
Higher rating valve[1,2]	270	100
Composition analyzer[3]	8,700	5000
IPA (per kg)[4]	1.72	-
E-G (per kg)[4]	1.24	-

[1]Source: U.S. EPA (EPA-450/3-82-010)
[2]Source: Leser Valve Pricing
[3]Source: Manufactured by Perkins and Grove
[4]Source: www.icis.com

TABLE 13. CALCULATED INVESTMENTS AND SAVINGS FOR EACH OPTION

Options	Investment	$	Savings	$	Reduction in concentration
1	SOL Column		Annual IPA and EG savings	422	0.0364%
	1. Pumps with double mechanical seals	1,600			
	2. Valves with higher rating (13 units)	5,486			
2	EXT and SOL Column		Annual IPA and EG savings	1,466	0.0746%
	1. Pumps with double mechanical seals	1,610			
	2. Valves with higher rating (28 valves)	110,360			
3	Solvent flowrate, 130 kmol/h	3,000	Annual EG savings	525	0.0004%
4	Composition analyzer	13,700	Annual IPA and EG savings	1,490	0.1064%

hand, the savings obtained refers to the amount of emissions prevented annually, reflected as loss of product and thus calculated as a function of the prevailing chemical price (Table 12). Table 13 shows the investments and saving for all options, which are also plotted on the impact diagram in Figure 3.

As shown in Figure 3, as the concentration of fugitive emissions decreases, the savings and investment made increases, as a function of the higher cost of piping and equipment that uses better sealing and sampling. The use of modern piping equipment will further reduce fugitive emissions, thus allowing more chemicals to be retained within the system. These are a few proposed modifications that could be looked into to reduce fugitive emissions. However, the best option will be determined on a case-by-case basis.

Final thoughts

A health-risk assessment based on fugitive emissions was carried out to estimate the potential hazard level of the system discussed here. The results used two different methods of estimation at different levels of the design phase. As seen from the comparison, the fugitive emission value is the lowest in the P&ID stage, as the estimation uses more accurate emission factor data. In addition, at this stage, the number and type of the piping components and fittings employed in the process are known more accurately. Processes with a HQ value <1.0 are considered to fall safely within the acceptable range.

Nevertheless, modifications can still be done to improve the system. Certainly, for cases where the calculated risk is beyond the acceptable range, optimization needs to be carried out to reduce the risk. Optimization may involve reduction of solvent fed, piping modifications and more, to reduce the fugitive emissions to safer level. This effort improves operation in process plants (by reducing potential losses of valuable materials) and helps to protect workers and the environment. ■

Edited by Suzanne Shelley

Risk estimation is vital for predicting the potential adverse health impacts workers may encounter as a result of potential fugitive emissions released from proposed process or plant designs

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Re-Establishing Course

Changing employment situations can leave affected employees trying to redefine their career paths. The positive experiences shared by these authors can provide some options and strategies

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The corporate world can be challenging because business fluctuates with time, and employment reductions must sometimes be made to get the business back on track. This leaves the affected employees in a difficult spot as they try to reestablish themselves and maintain a desired career path. This situation is doubly troubling for mature professionals (>30 years of experience) who face the added stigma of being viewed as past prime. During such challenging times, it is difficult to remember that bad things sometimes happen to good people, and "lemons can be turned into lemonade." The mature authors of this paper simultaneously faced the lost-job situation, but the outcomes were substantially different and both were positive. This article describes their experiences, which can serve as options for mature workers facing this traumatic situation and reestablishing course.

DOWNSIZING

The oil-and-gas sector in the chemical process industries (CPI) has made headlines in the economic pages of the news lately. The prices of crude oil and natural gas are widely publicized since they affect almost every aspect of human activity. Crude oil and natural gas are essential raw materials for the production of transportation fuels, fertilizers and a wide range of petrochemicals and polymers. These products are eventually converted into everyday products including plastics, packaging materials, textiles, fibers, paints, solvents and a host of specialty products.

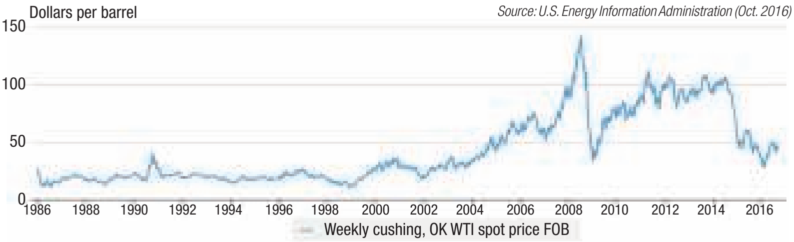

FIGURE 1. The price of crude oil, shown here with the Cushing Oklahoma WTI (West Texas Intermediate) price, has fluctuated greatly in recent years

Since the early 2000s, supply and demand of crude oil have fluctuated widely, resulting in a high degree of price volatility (Figure 1).

By contrast, the 1990s was a period of relative price stability. This allowed large corporations to develop projects and marshal the necessary human resources to achieve desired results. However, in the current environment when the price of crude oil has declined by a factor of four — from a high of $142 per barrel (bbl) in July 2008 to the current price of about $30–50/bbl — it is very difficult for corporations to remain profitable and provide steady employment. It must be remembered that in a capitalistic society, the first responsibility of a private corporation is to make money for the owners of the company. Unfortunately, sometimes this means having to reduce headcount as a way to lower overhead costs.

Corporate reaction

Most corporations try to resist downsizing, since it is disruptive to the organization as well as the individual employees. Furthermore, downsizing can have a negative impact on morale for even those employees who are not directly impacted. It is also difficult to recruit, train and motivate employees when the economy improves. Hence, most corporations reduce headcount only as a last resort. When this happens, the corporation tries to be humane and respectful to the affected employees by providing advance notice and a severance package to ease the transition. In the U.S., health coverage is continued under the Consolidated Omnibus Budget Reconciliation Act (COBRA), and unemployment compensation may be available for an extended period through the relevant state governments.

Transition

Very often both younger employees (<10 years work experience) and older employees (>30 years of experience) are impacted. Younger employees are usually more mobile and marketable. They usually find jobs faster than more senior, experienced employees who tend to be more specialized, less mobile and higher paid. This article focuses on the choices available to the more experienced employees.

OPTIONS

As experienced individuals explore options for the next phase of their careers, it is important to honor several important commitments. This includes abiding by the spirit and the letter of the contract with the previous employer. Non-compete agreements and non-disclosure agreements must be carefully and scrupulously honored. Also, under no circumstances should confidential and proprietary information and trade secrets, both of a business and technical nature, be divulged. If a certain matter is in doubt, it is better to err on the side of caution and get expert legal counsel. By divulging proprietary information, not only is the employee breaking the law, but is also compromising his or her integrity with a new prospective employer.

Determining a path forward for a mature professional who is seeking work is highly dependent on his or her personal situation. The following are some of the important questions that have to be considered:

- Does the individual face health issues or is the job seeker a primary caregiver?
- Does the individual still have children in school or a significant mortgage?
- Can the mature worker fall back on social security or spousal income for partial income and benefits, or is a full-time position needed?
- Is staying in the current location a must or is relocation or travel possible?

Answering these questions and others will determine the focus of the job search. Perhaps at this point in the person's career, it is possible to take on part-time work and devote more time to family and hobbies. This may also be a time when the individual would like to pursue business endeavors that have always interested him or her. Whatever the focus, the desired path should be mapped and pursued with strong drive. There are a lot of options to consider and some are depicted in Figure 2.

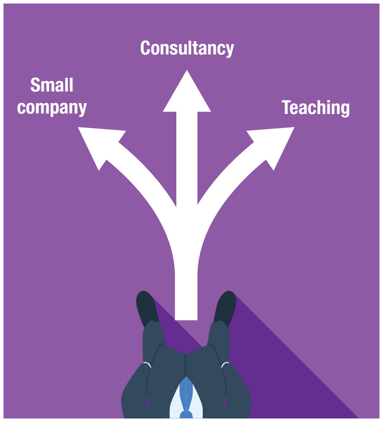

FIGURE 2. There are many options to consider when planning a change in career path

Look for a smaller company

Smaller companies are a very interesting option for an individual with several decades of experience with a large corporation. These people have in-depth knowledge of how large companies operate, their structure, strategy and systems. Very often, smaller companies lack these capabilities and really value the background of the experienced individual. Specific guidance can be provided in terms of how to develop an organization with roles and responsibilities, performance incentives, marketing research capability, marketing communications and customer relationship management. Very often these capabilities are undeveloped or non-existent in smaller companies. An experienced person

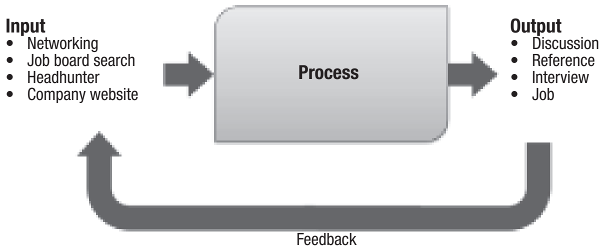

FIGURE 3. Those that put more effort into the process of job hunting can reasonably expect more of an outcome from those efforts

can quickly define the right solution and get results.

Start independent consultancy

Starting an independent consultancy is a possible path forward for the mature professional, and this path can offer a win-win situation for the individual and those being served.

For the individual, the consultant role can provide flexibility and the gratification of applying years of experience to solve problems. For the industry, there is often a valuable need for expertise that goes beyond current company knowledge. However, paychecks are not regular and are not guaranteed. Much of a consultant's time is spent in seeking opportunities and building relationships, none of which generate income. Hopefully at this point in the job seeker's career, she or he can live with this scenario.

Mature professionals should be aware that there is sometimes a stigma associated with consultants, and people taking this route should be aware of the perception by many. Alan Rossiter writes [*1*]: "Consultants are reputed to be the freewheeling cowboys of chemical engineering — grasping for big paychecks to squander on a lavish lifestyle." Consultants can help themselves by only becoming involved in areas where they have strong knowledge, and by saying no to requests that border on their knowledge base.

Teach at a local university

Some experienced individuals will choose to give something back to the community and their profession by teaching at a local university. While most universities require a Ph.D. degree to teach, it is possible to obtain an adjunct position with a community college based on lower degrees and experience. An experienced employee with several decades of industrial experience will bring a new perspective to solving increasingly complex day-to-day challenges. By bringing real-world experiences to theoretical book knowledge, classroom lessons will become more relevant and long lasting. This will help foster a spirit of curiosity so that students can continue to teach themselves all through their lives. Given that technology is changing things so rapidly, it will be essential for people to continually renew and refresh their education to be relevant in this fast-changing world.

SUCCESS FACTORS

The challenges for the mature worker to find the next job are huge and require a dedicated effort. There are often concerns that employers have regarding older workers even though they may not be verbalized. For example, will the mature worker get along with younger workers and bosses? Also, some believe the older worker will only do things the way they have done them in the past, and not stay current with technology. Finally, some believe that mature workers no longer have the grit and drive to bring the necessary energy to the job.

However, older workers bring attributes to the table that are not offered by younger workers. According to data from *Time* magazine [*2*], seven out of ten human resource (HR) managers surveyed say older workers have a stronger work ethic than their younger counterparts. However, less than 5% of companies have a strategy for keeping older workers. In November 2015, long-term unemployment stood at 38% for those ages 65 to 69 — a higher rate than for every younger cohort. This means the older worker must take more steps than his or her younger counterpart to find the next job.

Input / output model

Making a career change, especially at a later stage, is never easy. It is possible to apply the well-known input/output model to this situation. If there is no input applied in terms of searching, networking and training, and applying for jobs, the output will likely be zero. If greater input is applied, it stands to reason that there will be some positive developments. The relationship is not linear and there is a complex set of variables, such as skills, location and market demand that will determine the eventual outcome. However, by not applying effort, the results can be guaranteed to be non-existent. Hence it is very important to have a plan and make the effort in a systematic and disciplined manner (Figure 3).

A few guidelines

Here are some tips for mature workers to consider in looking for that next job:

Networking. By networking, we mean both old-fashioned networking and the new way people are networking, which is through social media. People in the mature category have established a significant number of contacts over the years. Now is the time to use them. The experience of the authors is that most people contacted during the job search are helpful, and if they themselves do not have a definite opportunity, they may point you to another contact who may have a strong work prospect. Just like fishing, the more hooks you put into the water, the greater the chance of landing that prize (a job), or at least getting reliable leads.

If you are serious about finding that next job, being represented on LinkedIn (www.linkedin.com) is a must. A study of HR managers showed that most employers use social networks as an integral part of the recruiting process. Among recruiters, nearly all said they use LinkedIn as their social network. But more than just being on LinkedIn, it is important that your information is current. Make sure you have a photo, and write a professional headline that is to the point.

Demonstrate knowledge of new technologies. A common complaint about older workers is that they do not stay current with the latest technologies, and insist on doing things the old way. It is important for the mature professional seeking employment to demonstrate they are progressive with their thinking. This can be done by writing a blog about your industry or by setting up a Twitter account where you follow others in your industry. The authors have found it effective to write industry papers demonstrating their current knowledge. There is no universal way to show current knowledge, but it is important to demonstrate this attribute during the job seeking process.

Show your knowledge of an old skill. This may sound like double talk based on the last section, but the real value offered by the mature professional is a skill or skills that cannot be found with younger workers. For example, perhaps there is a technical area in which you have specific talents that can help a company solve significant problems. This may be important to companies that are production-based and cannot afford to be stalled by downtime. Also, at this point in your career, you should be able to write clearly. This gives you a huge edge over the majority of younger applicants. The best way to highlight special skills is through a well written resume or a headline on LinkedIn.

Demonstrate your hustle and smart appearance. As pointed out earlier, there is often the perception that older workers no longer have an "A game." It is important that mature workers make it clear that they still have the passion. Also, make it clear that you can offer to work smarter than a new person with limited or no experience. Appearance is important, so make sure you do everything to show that you are a top player. You are selling the entire package of who you are, not just your work experience and talent. If you are not in shape, make an effort to get there. Update that wardrobe and come smartly dressed to interviews and networking meetings. You only get one brief moment to make that first impression, so make the most of it.

NEXT STEPS

Now that you made the choice of the path you would like to take, it is time to execute. Certainly much of the process is beyond your control because you cannot dictate outcomes. However, you can push things in your favor if you take the proper steps.

More than anything, know yourself. Emphasize accomplishments, not years of experience. We all have strengths and weaknesses, and it is easy to tout the positives. The real challenge is to buoy up your weaknesses so they do not become a detriment to being hired. Have discipline as you go through the hiring process. Finding that next job is difficult and particularly painstaking for the mature professional. Remain positive and approach the job search process as a full-time job. Creating daily "to do" lists and making daily accomplishments help to stay focused when there are setbacks along the way.

Finding another job

Finding a new job is similar to marketing a new product. You have to

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know your capabilities and match them against market needs. It is always important to provide value to the new employer and make sure that it is a win-win proposition. Otherwise, the arrangement will not last very long.

The first step is to get an interview. It must be remembered that the purpose of a resume is not to get a job, but to simply get an interview. For mature individuals who have been out of the job market sometimes for decades, it is important to prepare thoroughly for the interview. Being humble is not a virtue in the job market. At the same time it is important to be honest and not exaggerate your accomplishments. The deficiencies will soon be discovered anyway. It is a good idea to practice and be prepared with real life examples of success stories. Also, it is good to have a list of strengths and weaknesses with real examples illustrating these capabilities or lack thereof.

Once a job has been offered, it is good to consider all the features of the offer. This includes base pay, incentives, vacation, commute, flexibility, retirement plans, health insurance and other benefits. While most employers will be willing to negotiate some of these elements of the job offer, it is a good idea to always "step in the shoes" of the employer and make sure you are providing value in return for the total compensation package.

The first two to three weeks of a new job are very important. People are assessing the new hire and it is very important to make a good first impression. This includes bringing a good work ethic, professional bearing and a positive attitude. Most people will want the arrangement to be successful and will cooperate.

Independent contractors

If you have made the decision to become an independent contractor, there is a lot to consider. Above everything else, it is important to manage risk. Consider seeing an attorney who specializes in business startups, and also a business accountant. These individuals may recommend that you establish a limited liability company (LLC) to manage risk. However, this may not be sufficient to control risk and you may want to consider liability insurance. You may find this costly, so the best bet is to structure your client contracts so that you remain risk free.

Through your networking you may find various consultant opportunities, some of which border on your areas of expertise. It is okay to say no to areas where you are not fully competent. There is no shame in this and clients will actually respect you more for not "selling them a bill of goods." Consultancy offers a lot of independence, but you never stop looking for work. Even when you have a plate full of work, you always must be looking for the next opportunity.

While the independence of a consultancy may be viewed as a huge benefit, there may be scary moments in being on your own. There is no longer a person down the hallway that you can go to with a question. You are the "one stop shop," and you even have to handle all of your information technology (IT) problems. Communications are very important and you will use every form available including meetings, phone, email and social media. Some engineering professionals may feel uncomfortable with this, but as time goes on and relationships are established, this becomes easier and you may actually enjoy this part of the independence. Being an independent contractor can be very satisfying, but you will have to balance the rewards against the demands and challenges.

Keep networking

After finding that corporate position, or if you have established your own consultancy, continue to network. There are a few sides to this. First, you just went through a job loss and there is no telling when it could happen again. The next time it would be a benefit to be better prepared. Secondly, networking can help you get business in your new job, particularly if you are an individual consultant. Finally, now is a good time to offer support to others who are facing a job loss situation. Maybe it is a lost art, but people helping people is what life should be all about. As an example, in southeastern Pennsylvania there is an organization called CPENG (Career Professional Executives Networking Group; www.cpengroup.wildapricot.org/) whose sole purpose is to facilitate the networking process. Other areas likely have similar organizations.

The journey

An unexpected job loss can be devastating whenever it occurs, but for the older professional this can be particularly vexing because of the challenges of finding the next job at an advanced age. The mature authors of this paper faced a simultaneous job loss situation and took two separate paths in their job search, with both being successful. One re-entered the corporate world, but with a smaller company. The other chose to pursue consulting as an independent contractor. The key in both cases was extensive networking and intense focus in pursuing work. The authors were able to overcome the stigmas of the older workers by highlighting the benefits of their experience, and by "thinking young." Both authors continue to network and are always willing to help others on their journey. This is what professionalism is all about, and it should be a guiding principle for young and old. ■

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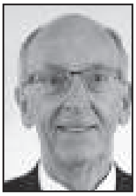

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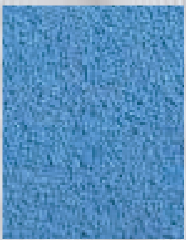

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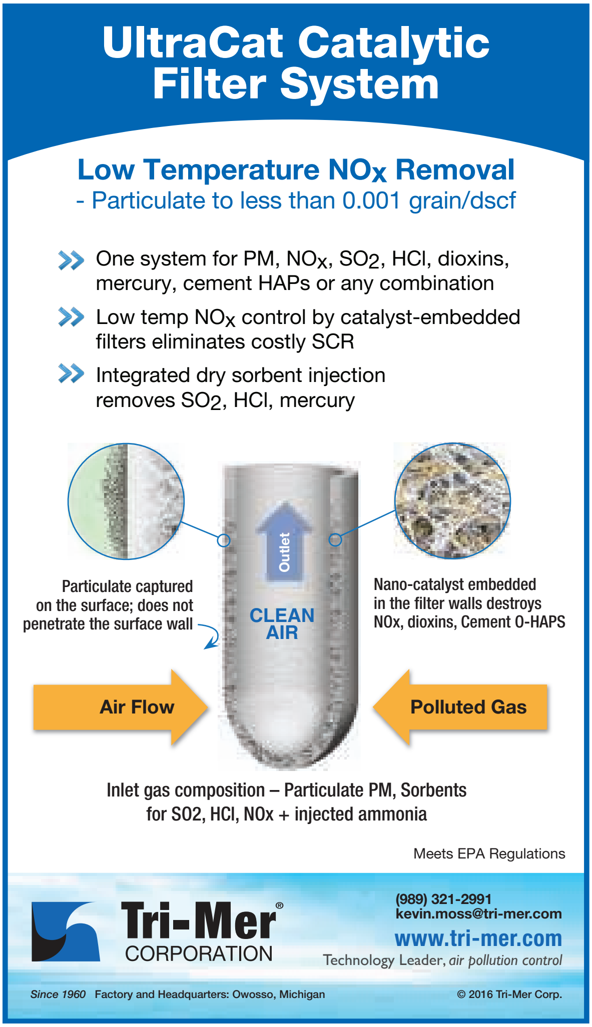

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Economic Indicators

2014 2015 2016

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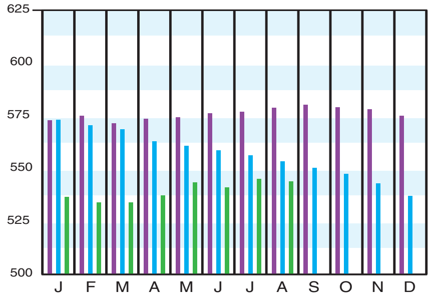
CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957-59 = 100)	Aug. '16 Prelim.	July '16 Final	Aug. '15 Final
CE Index	544.0	544.9	553.9
Equipment	649.1	650.4	665.6
Heat exchangers & tanks	558.4	560.3	592.2
Process machinery	653.0	652.7	658.2
Pipe, valves & fittings	817.4	822.8	822.3
Process instruments	391.3	389.2	392.1
Pumps & compressors	966.0	970.1	956.5
Electrical equipment	511.6	510.7	511.8
Structural supports & misc	708.5	707.9	733.2
Construction labor	328.1	328.9	323.4
Buildings	548.4	546.8	542.0
Engineering & supervision	314.8	314.4	318.2

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

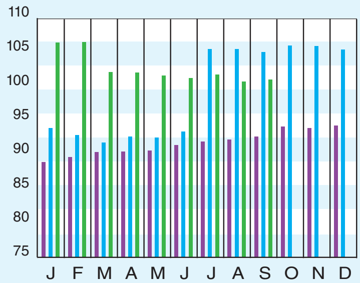
Annual Index:
2008 = 575.4
2009 = 521.9
2010 = 550.8
2011 = 585.7
2012 = 584.6
2013 = 567.3
2014 = 576.1
2015 = 556.8



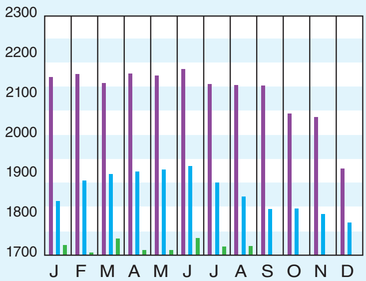
CURRENT BUSINESS INDICATORS

CURRENT BUSINESS INDICATORS	LATEST	PREVIOUS		YEAR AGO
CPI output index (2012 = 100)	Sept. '16 = 101.0	Aug. '16 = 100.5	July '16 = 101.2	Sept. '15 = 101.1
CPI value of output, $ billions	Aug. '16 = 1,722.8	July '16 = 1,719.0	June '16 = 1,739.8	Aug. '15 = 1,780.9
CPI operating rate, %	Sept. '16 = 74.2	Aug. '16 = 73.9	July '16 = 74.4	Sept. '15 = 74.6
Producer prices, industrial chemicals (1982 = 100)	Sept. '16 = 230.0	Aug. '16 = 226.6	July '16 = 223.2	Sept. '15 = 236.4
Industrial Production in Manufacturing (2012=100)*	Sept. '16 = 103.1	Aug. '16 = 102.9	July '16 = 103.5	Sept. '15 = 103.1
Hourly earnings index, chemical & allied products (1992 = 100)	Sept. '16 = 169.3	Aug. '16 = 168.4	July '16 = 169.6	Sept. '15 = 160.9
Productivity index, chemicals & allied products (1992 = 100)	Sept. '16 = 101.4	Aug. '16 = 101.4	July '16 = 101.5	Sept. '15 = 101.5

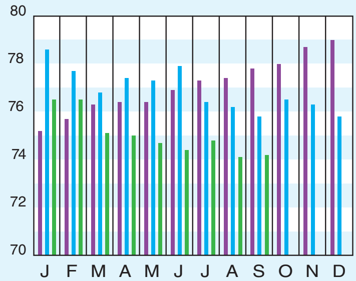
CPI OUTPUT INDEX (2000 = 100)†



CPI OUTPUT VALUE ($ BILLIONS)



CPI OPERATING RATE (%)



*Due to discontinuance, the Index of Industrial Activity has been replaced by the Industrial Production in Manufacturing index from the U.S. Federal Reserve Board.
†For the current month's CPI output index values, the base year was changed from 2000 to 2012
Current business indicators provided by Global Insight, Inc., Lexington, Mass.

CURRENT TRENDS

The August 2016 preliminary value for the *CE* Plant Cost Index (CEPCI; top; the most recent available) was slightly lower than a downwardly revised July number. Some equipment subcategories, such as Process Machinery and Electrical Equipment, saw small increases, while others, such as Pumps & Compressors, and Pipes, Tubes and Fittings, decreased slightly. The Construction Labor and Buildings subindices edged lower, while the Engineering & Supervision subindex was slightly higher. The preliminary August 2016 CEPCI value is 1.7% lower than the corresponding value from August of last year. Meanwhile, the latest Current Business Indicators (CBI; middle) for September 2016 showed a small increase in CPI Output index.