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Activated Carbon Fundamentals

page 32

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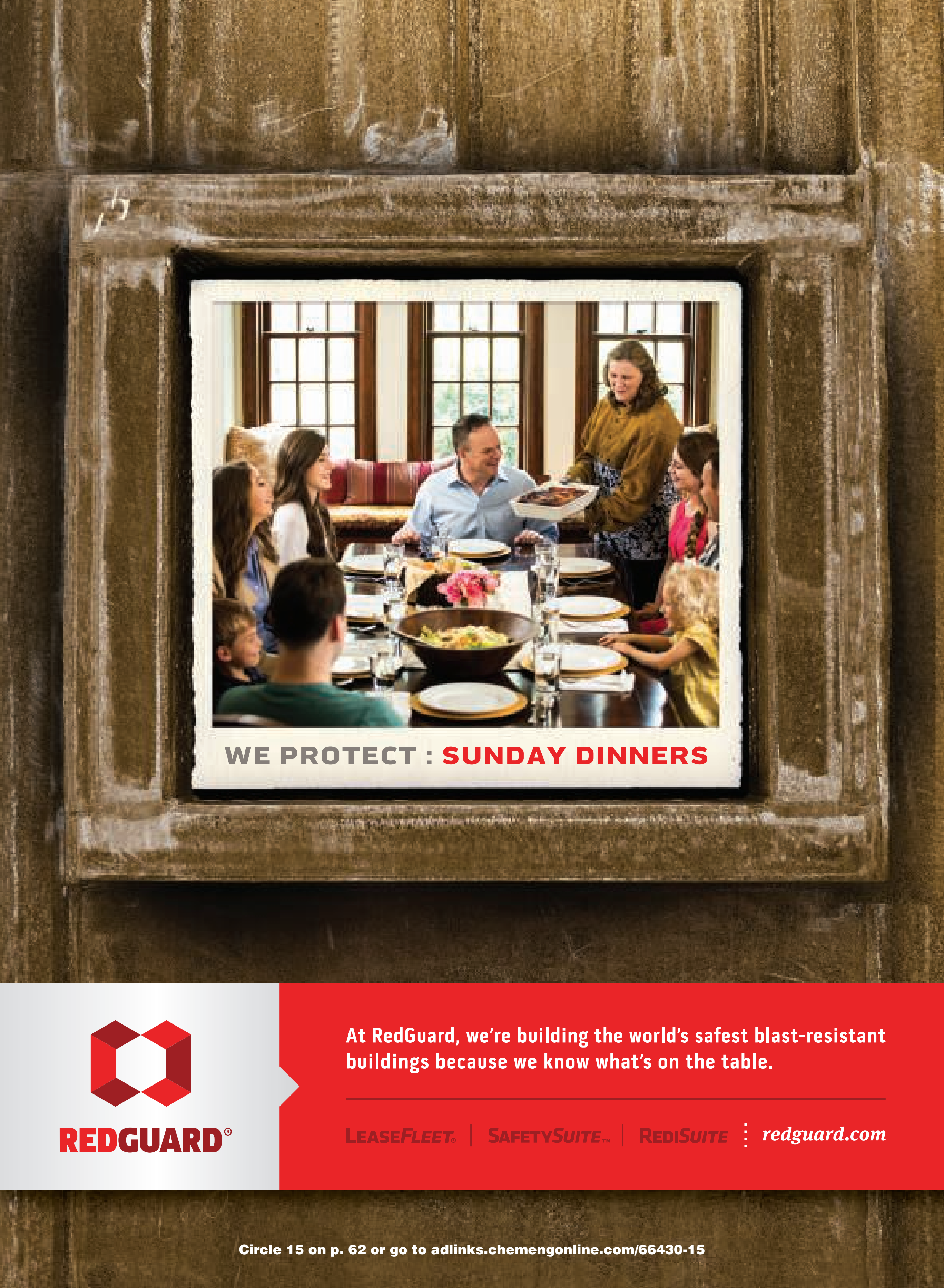
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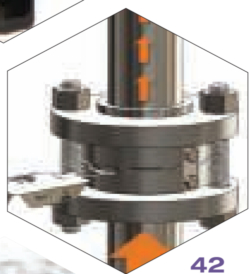
Cover Story

In the News


32


42


48

Technical and Practical

58

22

24

Equipment and Services

Departments

Advertisers

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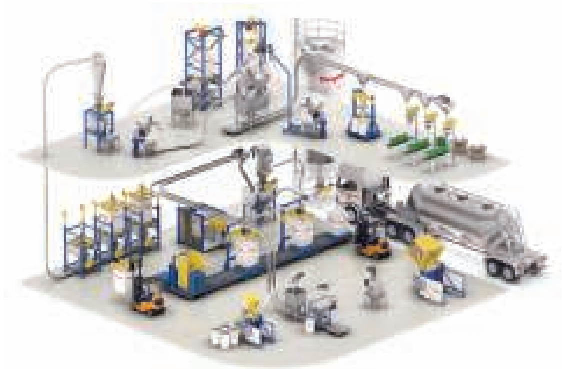

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CHEMICAL ENGINEERING
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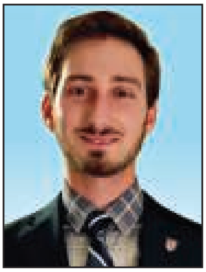
Editor's Page

2017 Nicholas Chopey Scholarship

As a provider of practical information and news for the chemical process industries (CPI) since 1902, *Chemical Engineering* strives to bring recognition to, and help advance the chemical engineering profession. One way we do this is by offering assistance to a student who is working toward a degree in chemical engineering. In 2007, *CE* established the annual Chopey Scholarship for Chemical Engineering Excellence, and we are happy to continue the tradition this year. The award is named after Nicholas P. Chopey, the magazine's former Editor-in-Chief, who devoted over 47 years of his professional career to *Chemical Engineering*.

The 2017 award winner



We are pleased to announce that this year's scholarship recipient is Dean Rufeisen, who is working toward his degree in chemical engineering at the University of Oklahoma. His expected graduation date is May 2018. Rufeisen is the president of the Oklahoma University AIChE chapter and a member of the university's Crimson Club, which promotes the history and traditions of the university. He was also the recent recipient of an Outstanding Junior Researcher Award. In addition to his academic achievements, Rufeisen is treasurer of the Alpha Epsilon Pi (Omega Upsilon Chapter) fraternity.

About the scholarship

The scholarship is awarded to current third-year students who are enrolled in a fulltime undergraduate course of study in chemical engineering at one of the following four-year colleges or universities, which include Chopey's alma mater and those of our editorial staff: the University at Buffalo, University of Kansas, Columbia University, University of Virginia, Rutgers University and the University of Oklahoma.

The scholarship is a one-time award. The program utilizes standard Scholarship America recipient selection procedures, including the consideration of past academic performance and future potential, leadership and participation in school and community activities, work experience, and statement of career and educational goals.

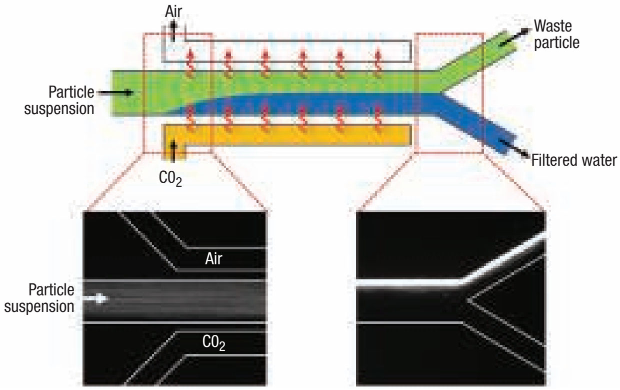
More information about the award, including how to apply and how to contribute a donation, can be found at www.chemengonline.com/npcscholarship.

In this issue

This month's cover story delves into the fundamentals of activated carbon. With its broad range of applications, an understanding of the basics of what activated carbon is and how it is manufactured, characterized and used can be helpful in applying this versatile sorbent. Our Feature Reports focus on safety, with a practical look at installing rupture discs and on sizing and installation of steam valves. Our Newsfronts cover the latest developments in nitric acid production, and in packaging equipment. You'll also find articles on modern training techniques that utilize virtual reality simulation and on setting product specifications. And as always, our pages include the latest technology news briefs, latest business news and more. We hope you enjoy reading. ■

Dorothy Lozowski, Editorial Director

Low-cost water treatment uses CO_2 to remove particles without membranes



Princeton University

Researchers at Princeton University (Princeton, N.J.; www.princeton.edu) have developed a water treatment technique that injects carbon dioxide gas into a stream of water to separate suspended particles that would be difficult to remove by sedimentation or by microbes. The system, built initially at laboratory-scale, removes suspended particles 1,000 times more efficiently than conventional filtration units, and does not require membranes, the research team says.

The low-cost, low-energy system could be used as a replacement to microfiltration and ultrafiltration, or as an adjunct to conventional filtration, protecting membranes from fouling. The system could also be used to separate waterborne bacteria and viruses without chlorination or treatment with ultraviolet light, the researchers say.

The system works by taking advantage of a principle called diffusiophoresis, whereby the movement of solid particles in water is induced by an ion concentration gradient. The ion gradient is set up by dissolving CO_2 gas in water, forming carbonic acid. The acid dissociates into hydrogen ions and HCO_3^- ions, similar to the chemistry that occurs in carbonated beverages. Large differences in the diffusivities of H^+ and HCO_3^- ions create a diffusion potential, which can be exploited to move suspended particles (which have significant surface charges) by diffusiophoresis, the researchers say.

The solids-containing water travels through a gas-permeable material (polydimethylsiloxane) and the ion gradient induces particle motion transverse to the flow direction. The particles then accumulate in one side of the channel, where they can be separated by splitting the water stream (see figure).

The research project was carried out in the Princeton laboratory of Howard Stone by post-doctoral researcher Sangwoo Shin, an engineering professor at the University of Hawaii at Manoa, and Orest Shardt, a former Princeton scientist now at the University of Limerick (Ireland). The research was described in a recent issue of *Nature Communications*. The team plans to scale up the technology.

Commercial debut for a process that captures CO_2 directly from air

On May 31, Climeworks (Hinwill/Zurich, Switzerland; www.climeworks.com) inaugurated its — and the world's — first commercial plant that captures CO_2 directly from air. The Direct Air Capture (DAC) facility, located at the waste-utilization plant of KEZO in Hinwill, Switzerland, will supply up to 900 metric ton per year (m.t./yr) of CO_2 to a nearby greenhouse-cultivation company, Gebr. Meier Primanatura AG, which previously had to purchase CO_2 delivered by trucks. CO_2 is used in greenhouses for increasing the growth of vegetables, such as tomatoes and cucumbers.

The DAC plant uses an air-filtration system that the company's founders first began developing while engineering students at the Swiss Federal Institute of Technology in Zurich (ETH; www.ethz.ch). The facility has 18 collectors, each equipped with a fan and a filter. The fans blow air through the filters, which are porous granulates modified with amines that absorb CO_2 from air. After a few hours, the filter becomes saturated. The captured CO_2 is then released by heating to 100°C using waste heat from the waste-utilization plant. The CO_2 is then pipelined to the greenhouses located 400 m away.

The plant will operate as a three-year demonstration project in cooperation with partners Gebr. Meier and KEZO, and with a contribution toward non-amortizable costs by the Swiss Federal Office of Energy.

Edited by:
Gerald Ondrey

RECYCLING SACHETS

Later this year, Unilever (London, U.K.; www.unilever.com) plans to open a pilot plant in Indonesia to test the long-term viability of its new technology for recycling plastic sachet (small bags) waste. The process, called CreaSolv, has been developed in cooperation with the Fraunhofer Institute for Process Engineering and Packaging (IVV; Freising, Germany; www.ivv.fraunhofer.de). The technology has been adapted from a method IVV developed to separate brominated flame retardants from waste electrical and electronic equipment. The pilot plant will enable the recovery of 6 kg of pure polymers using the same energy needed to produce 1 kg of virgin monomer, says IVV.

Today, only 14% of all plastic packaging is recycled globally, says Unilever. Sachets are widely used in developing and emerging regions of the world because they enable low-income consumers to purchase small amounts of products. In Indonesia, some 64 million m.t./yr of waste is generated, with 1.3 million m.t./yr ending up in the ocean. Unilever has pledged to make 100% of packaging recyclable, reusable or compostable by 2025.

UREA + SULFUR

Building on years of joint experience in the field of sulfur granulation, Sandvik Process Systems (Fellbach, Germany; www.process-systems.sandvik.com) and Shell joined forces and successfully demonstrated the integration of the Shell Thiogro (www.shell.com/sulphur/thiogro) Urea-ES technology and Sandvik Rotoform equipment during a series of continuous plant trials at Sandvik's productivity center in Fellbach. Shell's unique technology and

(Continues on p. 8)

the versatility of the Sandvik equipment enabled the production of Shell Urea-ES granules containing up to 70% of finely dispersed elemental sulfur in a urea matrix.

In the Sandvik Rotoform System, the homogeneous Shell Urea-ES emulsion is fed to the unit and deposited in the form of drops (2–4-mm dia.) across a steel belt cooler. Water is sprayed against the underside of the solid steel belt, ensuring no cross contamination either to product or to water. As the product moves along the steel belt, the liquid droplets are converted into solid pastilles. The final solid product is collected at the end of the belt and sent to the downstream handling system.

One standard Rotoform High Speed unit can produce up to 150 m.t./d of Shell Urea-ES granules. To support industrial deployment, Sandvik and Shell are finalizing their combined design to support installation in greenfield and brownfield projects, which will allow current and new Rotoform owners to expand their product portfolio by enabling the production of Shell Urea-ES fertilizer.

SCRUBBING SHIP'S SOx

Mitsubishi Heavy Industries, Ltd. (MHI; Tokyo, Japan; www.mhi.com) and Mitsubishi Hitachi Power Systems, Ltd. (MHPS; Yokohama, Japan; www.mhps.com) have jointly developed a large-scale, rectangular marine scrubber that efficiently removes oxides of sulfur (SOx) from the exhaust gases emitted by marine diesel engines.

The new SOx scrubber uses seawater as its cleaning agent, adopting a simple "open-loop" system in which seawater intake is sprayed directly on the exhaust gas. Effective use of seawater alkaline eliminates the need for chemicals or additional processing. Further, because the horizontal and vertical dimensions of the rectangular scrubber tower can be freely modified, volume efficiency is higher than previous cylindrical scrubbers, providing

(Continues on p. 10)

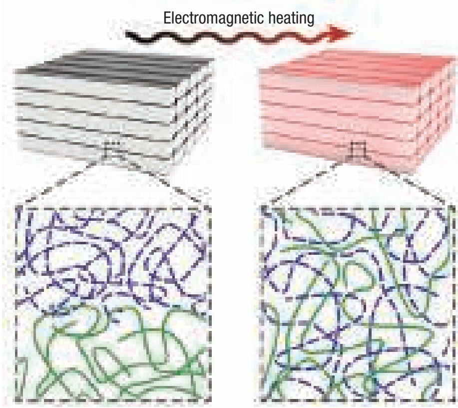
Responsive coatings lead to stronger 3-D-printed parts

Additive manufacturing (3-D printing) has quickly gained popularity, due in part to its potential for rapidly creating customized parts. However, one inherent limitation of additive manufacturing — specifically the high-speed fused deposition modeling (FDM) technique — is the potential for weak bonds between layers, which increases the likelihood of mechanical failure. With its FlashFuse technology, Essentium Materials LLC (College Station, Tex.; www.essentiummaterials.com) aims to enable stronger and tougher FDM 3-D-printed components by employing a sophisticated electric-welding technique along with proprietary filament materials coated with electromagnetically responsive carbon nanotubes (CNTs).

Electromagnetically heating the CNT skin on the filaments results in interlayer polymer diffusion, producing stronger welds between layers (diagram). Furthermore, the CNT coating enables targeted heating at potentially weak joints, allowing for improved interlayer polymer entanglements, making the finished parts even more resilient. "FDM 3-D printing can now attain the same level of utility and functionality for industrial applications comparative to traditional manufacturing methods," says Essentium Materials president and chief technology officer Blake Teipel. The company reports that its FlashFuse method creates 3-D-printed parts that retain up to 95% of the tensile strength of a comparable injection-molded part.

Essentium is partnering with BASF SE

Essentium Materials



(Lugwigshafen, Germany; www.basf.com) to develop advanced materials for 3-D printing applications. "The partnership's first wave of products will consist of varying flexible thermoplastic polyurethane grades, polyamides, carbon-fiber filled products and high-heat exotic materials," explains Teipel. Additionally, the company plans to launch FlashFuse filaments that incorporate BASF engineered resins later this year, which, according to Teipel, will be the first isotropic material offering for FDM 3-D printing when printed with Essentium's core technology. Essentium is also currently developing nanocellulose composites for additive manufacturing. The high strength-to-weight ratio of nanocellulose positions it as a potential sustainable replacement for other filament materials, such as carbon fiber or glass fiber, says Teipel.

A first commercial step towards on-site ammonia production

A new company — Tsubame BHB Co., Ltd. (Tokyo, Japan; www.tsubame-bhb.co.jp) — has been established to commercialize the world's first on-site production of ammonia for supplying amino-acid synthesis, fermentation materials and fertilizers. The company — a joint venture of Ajinomoto Co., Inc., No. 1 UMI Limited Partnership (both Tokyo) and professor Hideo Hosono at the Tokyo Institute of Technology (TiTech; Yokohhama) — began operations last April, and aims to implement first NH_3 production by 2021.

The production process will be based on a new catalyst that was developed in the laboratories of professor Hosono. The ruthenium-loaded electride — $12CaO{\cdot}7Al_2O_3$ (C12A7) — was found to be an order of magnitude more efficient than conventional Ru-based catalysts for ammonia production (for more details, see *Chem. Eng.*, December 2012, p. 12). The development is expected to enable NH_3 production at much milder conditions than the conventional Haber-Bosch process, thereby lowering costs.

Ajinomoto, a producer of amino acids (including glutamic acid) and fermentation materials, has been involved in the joint-development in order to be able to supply its NH_3 feedstock on site. The Japan Science and Technology Agency, which has funded the basic research, and TiTech have licensed patents for the new catalysts developed by Hosono's research group to the new company.

Electrostatic spray drying protects heat-sensitive products

A spray-drying technology that applies an electrical charge to feedstock as it exits the atomizing nozzle allows significant reductions in processing temperature and can eliminate downstream processing steps. The charge application can improve control over particle morphology, lengthen shelflife of products and lower energy consumption.

Fluid Air, a division of Spraying Systems Co. (Aurora, Ill.; www.fluidairinc.com), launched a new technology, known as PolarDry, in late 2016 after five years of internal development. The company is now testing PolarDry with products of potential users. These include heat-sensitive or easily oxidized compounds, such as proteins, active pharmaceutical ingredients, nutraceuticals, vitamins, antibiotics and chemicals.

As feedstock slurry and atomizing gas pass through PolarDry's nozzle, a charge is applied, so that each product-containing droplet has an electrical charge. Within the charged droplets, the molecules of high-polarity solvent (usually water) pick up a higher proportion of electrons and achieve a higher charge density, while the less polar product molecules pick up fewer electrons.

The repulsive forces of like charges drive the solvent to the surface of the droplet, while the spray-drying product tends to remain in the center, explains Joseph Szczap, director of operations at Fluid Air. "This creates an ideal situation for drying, and the solvent will evaporate efficiently at much lower temperatures — 80°C or even ambient temperatures — compared to traditional spray-drying processes," he says, which typically use temperatures of 200–250°C.

Fluid Air has also developed a method for applying the charge in a pulsed manner, so that a mixture of fast-drying (charge on) and slow-drying particles (charge off) is formed. "When the wet and dry particles collide, they form agglomerates," Szczap says, so users can spray-dry and agglomerate in the same vessel.

"Electrostatic spray drying technology will open up processing of a whole new branch of active ingredients that previously could not be produced in powder form due to the high temperatures of traditional spray drying," Szczap remarks, and may offer an economical alternative to freeze-drying that will dramatically cut processing time.

Also, PolarDry's conditions are well suited for microencapsulation applications. With lower temperatures, the encapsulated products retain higher levels of active ingredient. Requiring less raw materials results in considerable cost savings, says the company.

space savings. The equipment configuration is simple, allowing easy installation not only in newly commissioned ships, but in retrofitted vessels as well.

The new scrubber was developed in response to stringent new SOx emissions regulations that come into effect globally in 2020. It is able to purify exhaust gas emitted from inexpensive heavy fuel oil to a level equivalent to more expensive low-sulfur fuels.

MAKING CO FROM CO_2

Researchers from the École Polytechnique Fédérale de Lausanne (Switzerland; www.epfl.ch) have developed a new catalyst, based on abundant, inexpensive components, for the electrolysis of CO_2 into CO and O_2. Alternative bi-functional catalysts require more expensive materials, such as gold and silver.

The catalyst is made by depositing atomic layers of tin oxide on copper oxide nanowires. Tin oxide suppresses the generation of side-products, which are commonly observed from copper-oxide catalysts, leading to the sole production of CO in the electro-reduction of CO_2. The catalyst was integrated into a CO_2 electrolysis system and linked to a triple-junction solar cell (GaInP/GaInAs/Ge) to make a CO_2 photo-electrolyzer. The system uses the same catalyst as the cathode that reduces CO_2 to CO and the anode that oxidizes water to O_2 through the "oxygen-evolution reaction." The gases are separated with a bipolar membrane. The system was able to selectively convert CO_2 to CO with an efficiency of 13.4% using solar energy.

The work — described in a recent issue of *Nature Energy* — was funded by Siemens AG, and a Marie Skłodowska-Curie Fellowship from the E.U.'s Seventh Framework Program.

ALUMINUM BATTERY

The Industrial Technology Research Institute (ITRI, Chutung, Taiwan; www.itri.org.tw) and Stanford University (Palo Alto, Calif.; www.stanford.edu) have developed URABat, an aluminum battery that

(Continues on p. 11)

Finely tuned electrodes for water treatment

A new electrochemical water-treatment process developed in the laboratory of T. Alan Hatton, professor of chemical engineering at Massachusetts Institute of Technology (MIT; Cambridge; web.mit.edu), employs functionalized electrodes to selectively remove contaminants, such as pesticides and pharmaceuticals, at extremely low concentrations. The electrode surfaces are treated (functionalized) with Faradaic materials — those that can undergo both oxidation or reduction reactions to take on a positive or negative charge. These reactions take place at controlled potentials and can change the chemical properties of the Faradaic materials, making them selective toward a certain contaminant species at a certain oxidation state. "Depending on which Faradaic material you select to incorporate onto your electrodes, you can design the selectivity to a wide variety of contaminants, from organic pollutants to inorganic salts and heavy metals," explains MIT researcher Xiao Su. To treat the electrodes, a homogeneous dispersion of the Faradaic materials with carbon nanotubes in an organic solvent is used to coat conductive carbon fibers, which serve as current collectors and the support system for the functional materials. Then, a deposition process produces a porous film that provides high surface area for contacting the pollutant species, which are released from the system by applying reverse potential.

By functionalizing the cathode and the anode in a targeted asymmetrical fashion, both positively and negatively charged ions are simultaneously removed. In the work done at MIT, a ferrocene-based anode was used alongside a cobalt-based metallopolymer cathode. This specially synthesized cathode material has selective affinity for positively charged pesticides, says Su. The technology has been demonstrated at the laboratory scale, and the team is currently working on a prototype system with electrodes in the 10–100-cm^2 range. At the lab scale, the electrodes can undergo hundreds of cycles without the need for replacement, and the team aims to improve the system's chemical stability to withstand 5–6 months of continuous operation, according to Su.

CNT membrane aids distillation of brine

Membrane distillation (MD) — a thermal desalination technique used for recovering pure water from concentrated salt solutions — is hampered by high energy consumption, low single-pass recovery rates and by the need to use expensive heat exchangers to handle the high corrosivity of hot brines. A newly developed membrane based on carbon nanotubes (CNTs) layered with polyvinyl alcohol (PVA) can significantly simplify MD system design by eliminating heat exchangers, while also improving the water recovery rates by almost an order of magnitude.

The new membrane, developed by a research group at the University of California at Riverside (www.ucr.edu) led by David Jassby, could allow much more effective and efficient MD of brines, such as those from reverse osmosis waste and produced water from hydraulic fracturing operations. The researchers recently published details of the membrane in the journal *Nature Nanotechnology*.

Conventional MD works when hydrophobic membranes allow passage of salt-free water vapor, while preventing the passage of liquid water and salt. But the single-pass water recovery rates for membrane distillation are limited to 10% or lower, the researchers say. Also, MD's reliance on a constant stream of hot brine requires specially designed (and expensive) heat exchangers.

The new membrane is made by spraying carboxylated CNTs and PVA layer-by-layer onto a traditional PTFE (polytetrafluoroethylene) membrane as a support. The functional groups on the surface of the CNTs form crosslinks with PVA, generating a porous, hydrophilic and electrically conductive thin film. Coupled with the hydrophobic PTFE, membrane functions as a traditional MD system, where the vapor formation occurs at the CNT-PTFE interface. When a current is applied, the conductive CNT-based membrane acts as a Joule heater, generating heat at the membrane surface. In this way, the membrane heats only the brine in direct contact with the surface, dramatically increasing system efficiency. Salt rejection rates of 99% were observed experimentally using the CNT-based membrane, Jassby's group reports.

CNTs can degrade with the application of electric potentials, especially in ionizable environments (like brine), so the researchers found a method for applying the electrical potential using high-frequency, alternating-current (a.c.) electricity. This high-frequency a.c. allows for sufficient heating to drive the process, but also prevents degradation of the CNT membrane in brine solutions. Above a threshold frequency, electrochemical oxidation of the nanotubes was avoided, allowing the nanotube films to be operated for significant lengths of time with no reduction in performance, the researchers say.

A continuous biotreatment process that degrades phenol in wastewater

Although there are several ways to reduce the phenol concentration in industrial effluent, they each have drawbacks. Chemical treatment, such as adsorption and stripping, is fast but expensive, and the chemical degradation of phenol leads to the formation of toxic intermediates. On the other hand, biological treatment is economic and leads to complete mineralization of phenol, but the technique has been mainly limited to batch operations. There have been few studies involving a continuous phenol-degradation process by mixed cultures.

Now, a study by professors Bhaswati Chakraborty and Srabanti Basu from the Department of Biotechnology, Heritage Institute of Technology, (Anandapur, Kolkata City, India; www.heritageit.edu) compared the performance of a co-current and a counter-current continuous, packed-bed reactor (continuous reactor packed with solid waste) in degrading phenol by a mixed consortium of bacteria isolated from the East Calcutta wetlands. The degradation rates and removal efficiencies of phenol by soil bacteria from East Calcutta wetlands under various mean hydraulic retention times, air flowrates and temperatures were observed and processes were optimized for both co-current and counter-current conditions.

The researchers observed that the bacteria could degrade phenol at a higher rate in the co-current mode, with optimized conditions, including the following: a temperature of 30°C, substrate flowrate of 3.33 mL/min and a hydraulic retention time of 300.3 min. The rate of phenol degradation was 2 mg/L·min and the phenol removal efficiency was 82%.

To validate the performance of the co-current, continuous packed-bed reactor system in an actual industrial application, a phenolic industrial effluent was fed to the system in real time. The phenol degradation rate for this field trial was found to be 1.43 mg/L·min and the phenol removal efficiency was 72.85%. ■

uses an aluminum anode, a graphite-structured carbon cathode, and an ionic liquid electrolyte. According to ITRI, the battery can be fully charged in 1 min., and can be recharged up to 10,000 times. The electrode with graphitic foam material allows a 120°C fast-charging within 30 s. Single-cell discharge capacities of 200 mAh/g can be obtained and 30,000 times cycle life has been proven in the laboratory, says ITRI. The URABat offers several advantages over lead-acid batteries, which are not very environmentally friendly; and lithium batteries, because lithium is expensive and chemically unstable.

ITRI says the battery's stability can be attributed to aluminum's deposit (charge)/dissolve (discharge) reaction within ionized liquid of up to 99.8% coulombic efficiency. The anode does not cause dendritic crystallization, which quickly damages conventional batteries. ITRIsays the battery is inherently safe because all components, including the aluminum and graphite electrodes, and the isolating membrane, are inert. Ionic liquids can be eco-friendly solvents because of their low volatility, non-toxicity and non-flammable nature.

ITRI plans to establish a company to bring products to international markets. ❑

Business News

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Plant Watch

Ineos announces plans to build new PDH plant, increase ethylene capacity

June 12, 2017 — Ineos (Rolle, Switzerland; www.ineos.com) announced plans to construct a propane dehydrogenation (PDH) unit in Europe. The plant will produce 750,000 metric tons per year (m.t./yr) of propylene. Ineos also intends to increase the ethylene capacity of its cracker facilities at Grangemouth, Scotland and Rafnes, Norway to over 1 million m.t. each.

Kemira opens sizing-agent production lines in Nanjing

June 12, 2017 — Kemira Oyj (Helsinki, Finland; www.kemira.com) opened new production lines for the sizing agents alkyl ketene dimer (AKD) emulsion and cationic rosin at its production site in Nanjing, China. Sizing agents are used for improving water resistance in paper and board. In addition to these new production lines, Kemira plans to open a new alkenyl succinic anhydride (ASA) production line in Nanjing by the end of 2017.

Sasol begins construction on ethoxylation plant in Nanjing

June 8, 2017 — Sasol Ltd. (Johannesburg, South Africa; www.sasol.co.za) formally began construction of its new ethoxylation plant in Nanjing, China. The new plant is expected to be fully operational in early 2019. This project entails the construction of a new plant with a capacity of approximately 150,000 m.t./yr, with the option of using either branched or linear alcohols as raw materials.

Cabot breaks ground for new fumed-silica plant in China

June 8, 2017 — Cabot Corp. (Boston, Mass.; www.cabot-corp.com) and joint venture (JV) partner Inner Mongolia Hengyecheng Silicone Co. (HYC) broke ground on their new fumed-silica manufacturing facility in Wuhai, China. The companies are investing approximately $60 million in the new facility, which will have a capacity of 8,000 m.t./yr, and is scheduled to be completed in 2019.

Sibur to set up dioctyl terephthalate facility in Perm

June 8, 2017 — Sibur (Moscow; www.sibur.com) signed an investment contract to set up a new facility in Perm, Russia to produce 100,000 m.t./yr of dioctyl terephthalate (DOTP), a general-purpose plasticizer. Production is scheduled to start in 2019.

Dow finishes construction on new Freeport polyethylene unit

June 6, 2017 — The Dow Chemical Co. (Midland, Mich.; www.dow.com) completed the construction phase of its new polyethylene production facility in Freeport, Tex. The 400,000-m.t./yr unit is the first of four new derivative investments currently under way at Dow's sites in Texas and Louisiana.

BASF doubles processing capacity at catalyst-recycling site in South Carolina

June 5, 2017 — BASF SE (Ludwigshafen, Germany; www.basf.com) has completed an expansion at its Seneca, S.C. operation that will more than double the precious metals milling and sampling production capacity of the site. The Seneca site is BASF's global production hub for the recycling of end-of-life automotive and chemical catalysts, allowing for the recovery and recycling of platinum group metals.

Sadara starts up world-scale PMDI plant

June 1, 2017 — Sadara Chemical Co. (Jubail, Saudi Arabia; www.sadara.com) commenced commercial production of liquid polymeric methylene diphenyl diisocyanate (PMDI) at its Jubail chemical complex. Sadara's Jubail complex is considered to be the world's first fully integrated PMDI manufacturer, combining units that produce nitric acid, mono-nitrobenzene, formalin, benzene, aniline and chlorine, as well as hydrogen and carbon monoxide.

BASF and Sinopec to increase propionic acid capacity at Nanjing site

June 1, 2017 — BASF-YPC Co., a 50-50 JV between BASF and Sinopec, will increase propionic acid production capacity by 30,000 m.t./yr in Nanjing, China. The expansion will go onstream in 2019. With this expansion, the propionic acid production capacity at the Nanjing site will increase to 69,000 m.t./yr.

AkzoNobel completes organic peroxides expansion in Mexico

May 31, 2017 — AkzoNobel's (Amsterdam, the Netherlands; www.akzonobel.com) Specialty Chemicals business has completed an organic peroxides expansion project at its Polymer Chemistry production facility in Los Reyes, Mexico. The investment will increase the company's peroxyester capacity in North America by 40%.

Chevron Phillips increases organosulfur capacity at Tessenderlo site

May 24, 2017 — Chevron Phillips Chemical Co. (The Woodlands, Tex.; www.cpchem.com) has expanded its Tessenderlo, Belgium plant by debottlenecking its production unit for ethyl mercaptan and tetrahydrothiophene. This expansion increased production capacity for these products by 65%.

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ExxonMobil completes two new polyethylene lines in Mont Belvieu

May 23, 2017 — ExxonMobil Chemical Co. (Houston; www.exxonmobilchemical.com) announced the mechanical completion of two new 650,000-m.t./yr high-performance polyethylene lines at its plastics plant in Mont Belvieu, Tex. The company expects production to begin during the third quarter of 2017.

Mergers & Acquisitions

Honeywell to boost cybersecurity portfolio with Nextnine acquisition

June 12, 2017 — Honeywell (Morris Plains, N.J.; www.honeywell.com) has agreed to purchase Nextnine, a specialist in industrial cybersecurity. Nextnine's flagship technology, ICS Shield, protects industrial sites from cybersecurity attacks and enables remote monitoring of assets.

Shenzen Capchem to purchase electrolytes plant from BASF

June 5, 2017 — BASF has signed an agreement to sell its electrolytes manufacturing site in Suzhou, China to Shenzhen Capchem Technology Co. The transaction is expected to close during the third quarter of 2017.

Hexcel to acquire French composites producer Structil

June 2, 2017 — Hexcel Corp. (Stamford, Conn.; www.hexcel.com) has entered into exclusive negotiations to acquire composites producer Structil S.A. Structil is a JV between Safran Ceramics and Mitsubishi Chemical Corp. that is headquartered in Vert-le-Petit, France. Structil's 2016 sales were approximately $21 million.

Chromalox acquired by Spirax-Sarco Engineering

May 30, 2017 — Spirax-Sarco Engineering plc (Cheltenham, U.K.; www.spiraxsarcoengineering.com) signed an agreement to acquire Chromalox, Inc. (Pittsburgh, Pa.; www.chromalox.com) for $415 million. Chromalox is a provider of products and systems for industrial process heating and temperature management with manufacturing facilities in North America, France and China.

PPG to sell U.S. fiberglass operations to Nippon Electric Glass

May 26, 2017 — PPG Industries, Inc. (Pittsburgh, Pa.; www.ppg.com) has reached a definitive agreement to sell its remaining fiberglass operations to Nippon Electric Glass Co. (NEG), including manufacturing facilities in South Carolina and North Carolina. Pre-tax proceeds from the sale are approximately $545 million.

Clariant and Huntsman to combine in merger of equals

May 22, 2017 — Clariant AG (Muttenz, Switzerland; www.clariant.com) and Huntsman Corp. (The Woodlands, Tex.; www.huntsman.com) approved an agreement to combine in a merger that will create a global specialty chemicals entity named HuntsmanClariant with a combined enterprise value of approximately $20 billion. The transaction is targeted to close by year-end 2017. ■

Mary Page Bailey

Nitric Acid in the Spotlight

Efforts continue to make nitric-acid production more efficient with lower emissions of greenhouse gases

thyssenkrupp Industrial Solutions

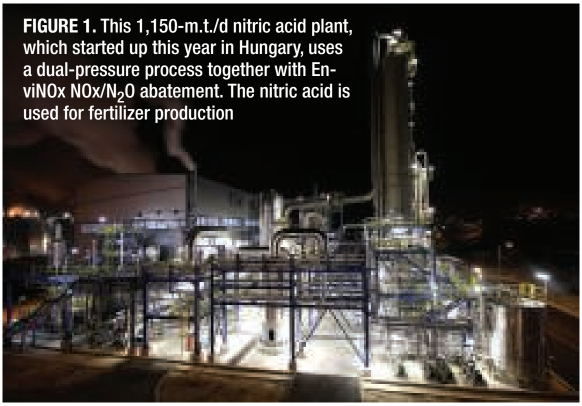


FIGURE 1. This 1,150-m.t./d nitric acid plant, which started up this year in Hungary, uses a dual-pressure process together with EnviNOx NOx/N_2O abatement. The nitric acid is used for fertilizer production

Like the ammonia used to make it, nitric acid (NA) continues to be produced by a process nearly a century old — the Ostwald process. Although the basic chemistry has not changed over the last century, the process technology certainly has. On the one hand, NA license providers continue to find ways to improve the energy efficiency and yields, as well as make the production plant more reliable. On the other hand, catalyst providers continue to improve the composition and structure of their catalysts to boost yield, while reducing the formation of harmful byproducts. And more recently, engineering companies and catalyst manufacturers have combined their skills to reduce the emissions from NA plants.

Applications of HNO_3

Nitric acid is used for a large number of applications, but the majority of the acid is used for making fertilizers (Figures 1 and 2). Around 80% of the NA produced globally is used for making ammonium nitrate, which is the second-largest nitrogen fertilizer after urea, says Mark van Denderen, head of marketing, Stamicarbon B.V. (Sittard, the Netherlands; www.stamicarbon.com). About 75% of the ammonium nitrate produced is used in fertilizers, and the rest for making explosives that are used in the mining industry, he says.

The demand for plants that produce 60 wt.% NA for fertilizer manufacture remains strong, says Michael Groves, head of nitric acid at thyssenkrupp Industrial Solutions AG (Essen, Germany; www.thyssenkrupp-industrial-solutions.com). An increasing interest in higher concentrations — typically 68 wt.% — has, however also been observed, he says. This 68 wt.% is the maximum concentration possible to produce via the conventional Ostwald process, says Groves, and thyssenkrupp has a patented process for making this azeotropic concentration — a variation of the Ostwald process — that prevents the concentrated 68% HNO_3 emerging from the absorption tower from being diluted by high levels of water vapor in the atmospheric air used in the plant, he says.

"On the part of some fertilizer companies, we are seeing an interest in diversification," explains Groves: either for new plants or for revamping existing plants to be able to produce different concentrations simultaneously — 60% for fertilizer manufacture and a higher concentration, typically 68%, for organic nitration to produce, ultimately, polyurethane foams and other products.

For many applications, such as the production of explosives, pigments and rocket fuels, higher concentrations are required, says Edgar Steffin, head of marketing, QVF, De Dietrich Process Systems GmbH, Mainz, Germany; www.dedietrich.com). De Dietrich supplies plants that achieve 99.8% HNO_3 concentration using reactive rectification with sulfuric acid. Plants for these QVF processes are built with highly corrosion-resistant components (columns, packing and piping) made from QVF borosilicate glass 3.3 and De Dietrich glass-lined steel.

More recently, we are seeing a demand for purified, high-concentrated nitric acid for the semi-conductor industry, says Steffin. "They require a maximum metal content of less than 1 part per billion (ppb), and even down to less than 0.1ppb," he says.

Ammonia oxidation

Large-scale NA production is still performed using the Ostwald process (Figure 3), whereby NH_3 is first oxidized with air over a platinum catalyst at temperatures of around 900°C. NH_3 combustion forms oxides of nitrogen [NOx; Reactions (1) and (2)], which is then absorbed in water to form HNO_3 [Reaction (3)]:

$$4NH_3 + 5O_2 \rightarrow 4NO + 6\,H_2O \quad (1)$$

$$2NO + O_2 \rightarrow 2NO_2 \quad (2)$$

$$3NO_2 + H_2O \rightarrow 2HNO_3 + NO \quad (3)$$

How these three steps (all exothermic) are performed is the basis of today's different NA production processes. These processes can be broadly categorized as monopressure, in which combustion and absorption take place at the same pressure (typically 4–6 bars) or dual pressure, in which combustion occurs at a lower pressure (4–6 bars) than that of absorption (10–14 bars). The oxidation reaction is more favorable at lower pressures, whereas absorption is more efficient at higher pressure, explains Paz Munoz, a process engineer at Stamicarbon. Deciding between the two processes is a tradeoff between capital expenditures (capex), and operating costs (opex), which are related to the costs of feedstock, utilities and energy, says Stamicarbon's van Denderen.

Dual-pressure processes

The general trend today is for bigger plants, and companies are looking closely at the total cost of ownership, says van Denderen. "That means efficiency [of the NA plant] is very important." Dual-pressure technology is especially competitive for production capacities of 500–600 metric tons per day (m.t./d) and upwards, he says. With this in mind, Stamicarbon has revitalized its dual-pressure technology, he says.

Munoz will introduce Stamicarbon's newest dual-pressure process at the Ammonium Nitrate — Nitric Acid Producers Group (AN-NA) conference (October 1–6; Austin, Tex.), with a presentation entitled "An improved dual-pressure nitric acid process with maximum energy recovery." The company declined to reveal any details in advance, but van Denderen says that "the energy efficiency of our design is unbeatable."

Last year, Weatherly Inc., a wholly owned subsidiary of KBR Inc. (Houston; www.kbr.com) also introduced a new dual-pressure technology for producing NA at a large scale.

KBR Weatherly's dual-pressure process (for more details, see *Chem. Eng.*, October 2016, p. 8) is said to deliver lower operating costs with its more efficient heat-recovery design. Tailgas exits the system at 620°C, compared to the lower (490°C) temperature of alternative processes. This enables more efficient recovery of heat that is subsequently used to generate energy to power up the system. As a result, the new process offers an operating cost advantage over competing technologies of $4–5/ton of NA produced, says the company.

"Over the past 20 years, about a quarter to a third of the plants [built by thyssenkrupp] have been mono pressure, but the trend is toward dual pressure plants," says thyssenkrupp's Groves. "For small plants (up to around 500 m.t./d) we would still consider mono-pressure design," he says.

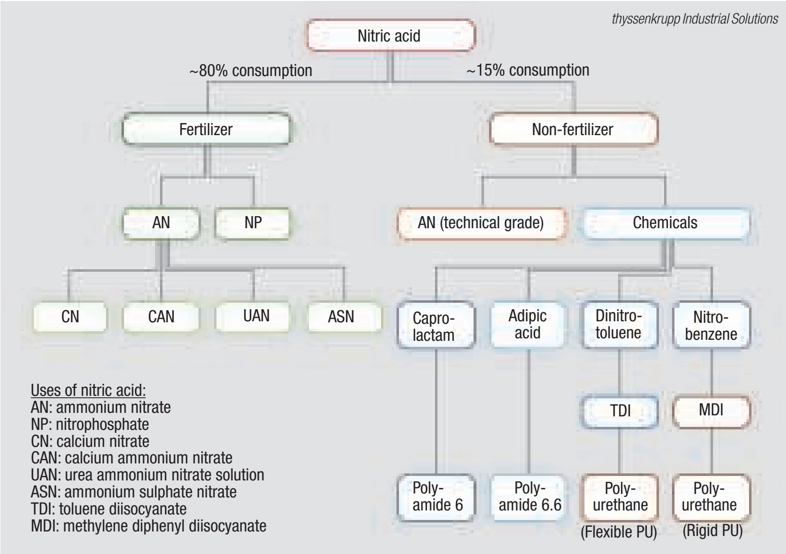


FIGURE 2. Nitric acid is used for a number of applications, with the bulk going into the production of fertilizers

The present style of dual-pressure plant with a sieve-trayed absorber was introduced in the 1970s, Groves says. "Of course, there have been many improvements," he adds.

Ammonia oxidation catalysts

The NH_3 oxidation catalyst is typically a gauze composed of platinum group metals (PGMs). Over the decades, the gauze has been refined and optimized. For example, Hereaus GmbH (Hanau, Germany; www.heraeus.com) first began supplying Pt-wire gauzes for NH_3 oxidation in 1916, and subsequently replaced the Pt wire with platinum-rhodium wire gauzes in 1928. Today, the company now supplies gauzes with diameters greater than 6 m. In the 1990s, Hereaus introduced its FTC (functional total control) gauzes designed to reduce the formation of N_2O emissions by 50%. (N_2O is a combustion by-product that is a greenhouse gas (GHG) with a global-warming potential (GWP) that is 265 times higher than CO_2.) More recently, Heraeus also introduced a secondary catalyst that reduces N_2O emissions by up to 95%.

Johnson Matthey plc (JM; London, U.K.; www.matthey.com) also offers a variety of Pt-based gauzes with unique production and knitting patterns. For example, its Eco-Cat technology uses palladium in a controlled manner to replace some of the Pt in the gauze. Exploiting its metal-recovery properties, the Pd catches lost Pt without compromising the NH_3 conversion. This increases the gauze performance and gives a sustainable and efficient system for NA production, says the company.

In 2014, the Platinum Engineered

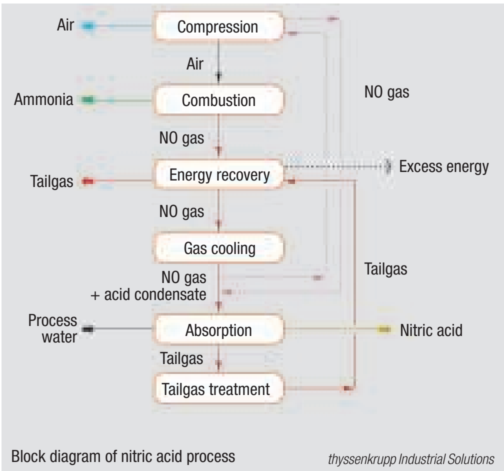


FIGURE 3. Industrial production of nitric acid uses the Ostwald process, which involves ammonia oxidation, followed by absorption of NO_2

A GLOBAL INITIATIVE TO REDUCE N_2O EMISSIONS

In December 2015, the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB; Berlin, Germany; www.bmub.de) established the Nitric Acid Climate Action Group (NACAG; Berlin, Germany; www.nacag.org), with the aim to assure global abatement of N_2O emissions from nitric-acid production by 2020. The initiative offers all governments and plant operators guidance and information on technological and regulatory questions regarding N_2O abatement. It also provides financial support to facilities in countries that are not able to bear the associated costs of abatement technology by themselves, says Volker Schmidt, adviser for NACAG, Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GEZ; Berlin, Germany; www.giz.de). Last September, the German Chemical Industry Assn. (VCI; Frankfurt; www.vci.de) joined the NACAG — the first industry association to "jump on the train", says Schmidt. "This is a good example of cooperation between industry and government."

Globally, the cumulative N_2O abatement potential is estimated at 300–400 million m.t. of CO_2 equivalents (CO_2eq) between 2016 and 2020 and 600–800 million m.t. of CO_2eq between 2021 and 2030, according to NACAG. The initiative wants to help companies get started by providing financial support, which comes with the caveat that the national governments of the countries in which the respective plants are located will make a commitment for continued abatement after 2020, says Schmidt.

According to NACAG, the most successful example of comprehensive N_2O abatement to date is the E.U., where N_2O emissions from NA production are covered by the E.U. Emissions Trading System. Over recent years, this has achieved the consistent abatement of around 90% of N_2O emissions in the E.U. A number of countries intend to follow the E.U.'s example. Of the 580 NA production plants operating around the world, around 140–160 (mostly in the E.U. and a few in North America) have already implemented N_2O reduction, estimates Schmidt.

N_2O emissions from NA production can be reduced relatively easily and at a low cost compared to other GHG abatement options, says Schmidt. Technical abatement costs range from €0.90 to 3.20/tCO_2eq depending on the employed abatement technology and specific plant characteristics, according to NACAG.

There are two main abatement techniques: secondary controls reduce the N_2O directly after it is formed in the oxidation reactor; and tertiary controls reduce N_2O by installing a catalytic reactor either upstream or downstream of the tailgas expansion unit following the absorption stage at which the final product NA is produced.

The most common secondary N_2O abatement catalyst technology consists of a base metal catalyst made of cylindrical pellets. Its operation requires no additional heat or energy input. The very high temperature levels inside the ammonia oxidation reactor are sufficient to ensure effective operation. The abatement efficiency can reach more than 98%, but is usually lower, varying from plant to plant depending on different factors. Heraeus, for example, introduced such a catalyst in 2005 that achieves a 95% N_2O reduction, and has been successfully used in a number of plants, says the company.

We are now preparing for a big information campaign, says Schmidt. "Over the next few weeks, we will be distributing information to all plant operators and governments around the world that are eligible for the financial-support option of the initiative. We are also inviting all parties and stakeholders to contact the NACAG secretariat for further elaboration of options and possibilities," he says. For more information, go to www.nitricacidaction.org. ❑

Materials division of Umicore AG & Co. KG (Hanau-Wolfgang, Germany; www.pem.umicore.com) introduced a new gauze generation for catalytic NH_3 oxidation. Compared to the company's established MKS systems, the new Multi-Combination Gauze Pack (MPAC) technology is said to allow a larger number of combinations, designs and functionalities of gauzes, including separators, getters, and the platinum gauze itself. By selecting the right combination of gauzes for a given application, the new catalyst system is said to improve product yield with a lower weight of PGMs and reduced N_2O emissions.

Reducing emissions

"In all parts of the world, we are seeing an increased emphasis on lower NOx and N_2O emissions," says thyssenkrupp's Groves (see box above). The company offers two variants of its EnviNOx process, both of which reduce tailgas N_2O emissions to below 30 ppm, while also reducing NOx emissions. Since the process was first commercialized in 2003 (*Chem. Eng.*, November 2002, p. 19), there are now about 30 EnviNOx systems in operation around the world.

Now that the issue of NOx and N_2O emissions in steady continuous operation has to all intents and purposes been solved with the EnviNOx process, there still remains the problem of transient emissions of NOx at plant startup and shutdown, says Groves. Such emissions are troublesome, especially for plants located in populated areas, due at least in part to the unsightly brown plume of NOx-containing gas exiting the plant stack. The company is now performing ongoing development work aimed at reducing such emissions safely without, for example, the risk of forming ammonium nitrate by inappropriate operation of the NOx abatement system, he says.

NOx abatement and N_2O abatement are now a requirement on nearly all new plants (certainly within the U.S. and Europe), says David Boyd, director of Operations, KBR Weatherly. Current emissions standards in the U.S., for instance, are requiring greater than 98% removal of NOx and N_2O, he says. Catalyst manufacturers are answering the call for the lower emission limits with enhanced catalysts.

For example, Clariant AG (Munich, Germany; www.clariant.com) has been developing N_2O abatement technologies for over a decade. The company collaborates with its partner thyssenkrupp Industrial Solutions to provide tertiary N_2O abatement solutions at more than 25 NA production plants globally. Combined, the installations reduce annual N_2O emissions equivalent to approximately 15 million tons of CO_2.

In August 2015, Clariant introduced EnviCat N_2O-S, a secondary catalyst that can be easily installed in existing NA plants without revamping the facility, and converts the majority of N_2O generated into harmless N_2 and O_2. At the same time, the catalyst reduces NH_3 requirements for the same amount of NA production, thus considerably lowering operating costs, says the company.

Meanwhile, Haldor Topsoe A/S (Lyngby, Denmark; www.topsoe.com) recently introduced TertiNOx, a new catalyst for reducing both NOx and N_2O emissions from the tailgas of NA plants. Unlike traditional pellet-type catalysts, TertiNOx is a monolith structure that is impregnated with iron zeolite that enables a simpler, smaller and less-expensive reactor design (see *Chem. Eng.*, May 2017, p. 10). ■

Gerald Ondrey

Packaging Equipment: Product Quality Improves with Innovations

More sophisticated packaging equipment helps the CPI boost product quality and machine reliability

When it comes to packaging their products, chemical, pharmaceutical and food processors list product quality, often directly related to health and human safety, as the top concern, followed closely by efficiency and reliability of equipment. Always aware of these needs, manufacturers of packaging systems are adding sophistication to their equipment to help meet chemical process industries' (CPI) requirements.

"Human health and safety are of highest importance to processors," says Stefan Bauer, sales director, chemical solutions, with Optima Consumer GmbH (Schwabisch Hall, Germany; www.optima-packaging.com) "Furthermore, highly reliable, flexible and safe equipment secures processors' daily business and produces top-quality products."

To ensure these goals, Bauer says packaging equipment providers are working on innovations based on robotics, product transport systems, integrated solutions and the incorporation of servo technology combined with clever software solutions. "This results in equipment with a small footprint, high product and format flexibility and track-and-trace capability, as well as full process control," he says. "In addition, product data management, condition monitoring, track and trace, serialization and batch size 1 (the economically efficient production of highly customized products) are no longer just buzzwords. They are currently available solutions," Bauer adds (Figure 1).

Quality through sophistication

It's no secret that the CPI — especially chemical, pharmaceutical and food processing — are highly regulated by global and local agencies, so fulfilling external and internal regulations is crucial to ensuring product quality and human health and safety.

For example, cross-contamination is often a big issue, says Optima's Bauer. "clean in place (CIP) is a standard feature in our liquid filling equipment and sometimes sterilization in place (SIP) may also be required," he says. "We also offer trolley solutions in which all machine parts in direct contact with the product — for example in filling systems — are located on an exchangeable trolley. The trolleys can even be coded, which means the machine control will only accept a correctly identified trolley for a specific product. While one trolley is in operation, other trolleys can be cleaned offline. With this procedure, the uptime of the equipment is increased, while cross contamination and all the related risks are avoided."

Optima Consumer

FIGURE 1. Packaging equipment providers are working on innovations based on robotics, innovative product transport systems, integrated solutions and incorporating servo technology combined with clever software solutions

Bauer says quality control systems are also important. "Net weigh systems for liquids or powders, torque control devices, track-and-trace solutions, camera control systems, checkweighing and further quality-increasing features are available," says Bauer. He adds that, if required, line control systems can verify each process. "All measurable quality parameters can be tracked and documented. Only if a process is conducted with a pre-defined limit, can the next process step be released by the system."

Markus Schade, head of market man-

IN BRIEF

QUALITY THROUGH SOPHISTICATION

RELIABILITY AND EFFICIENCY

Mettler-Toledo

FIGURE 2. The C3570 checkweigher uses precision and speed to weigh products in all types of packaging

Bosch Packaging Technology

FIGURE 3. To combat counterfeit pharmaceuticals, Bosch has developed CPI Track & Trace software for pharmaceutical manufacturers and contract packagers

agement at Mettler-Toledo Garvens GmbH (Giesen, Germany; www.mt.com/vn/en) agrees that quality can be improved via added sophistication of packaging equipment. "Checkweighers play a key role here, as they enable processors to produce products within a defined range from a fill-level perspective," he says. "Consumers expect to receive exactly the amount of product they paid for, therefore, monitoring and correcting fill levels and ensuring the repeatability of that process is a critical element." (Figure 2)

In addition, he says, machine safety regulations and weighing regulations must be fulfilled, so most processors follow the Measuring Instruments Directive (MID) approval to produce products in a defined range for under and overfilling. But where the real advances come in is in the combining of technologies to ensure quality. "Checkweighers, for example, can be linked to vision systems," says Schade. "Vision systems are able to check if labels are correct, which is particularly useful where product changeovers are concerned. Many processors run multiple products on the same lines, therefore when there is a changeover, the checkweigher will recognize that the product is different due to its programming. What may not be picked up is if the label has not changed correctly, which could lead to potential problems. A vision system, in conjunction with the checkweigher, is able to detect this while, at the same time, checking the quality of the label and its readability."

The pharmaceutical industry is strongly regulated, because quality correlates with patients' health, says Johannes Rauschnabel, chief pharma expert with Bosch Packaging Technology (Waiblingen, Germany; www.boschpackaging.com). For this reason, all kinds of quality attributes are the focus of regulatory bodies. "In-process control is superior to quality by sampling. Aseptic quality is a key requirement for sterile liquid formulations. This means disinfection of the process environment, all manufacturing equipment and filtration. In-line inspection techniques, as well as final inspection of vials, ampoules, cartridges and syringes for cosmetic defects or container closure integrity (CCI) ensure high quality," he notes.

CCI is extremely important in this industry to ensure sterility and stability — and thus quality and safety. "It requires the inspection of a large number of parameters. The United States Pharmacopeia has revised its general chapter 1207, demanding more quantitative, non-destructive CCI test methods."

To help meet these needs, Rauschnabel says Bosch offers an entire range of technologies based upon their expertise of visual inspection and CCI. Examples are high-voltage leak detection or headspace analysis. But perhaps the greatest areas of innovation are in the automation and connectivity of packaging equipment, suggests Rauschnabel.

"Industry 4.0 solutions bring more intelligence and transparency into production to ensure quality and safe manufacturing processes. To combat counterfeit pharmaceuticals, for example, Bosch has developed a specific track-and-trace solution (CPI Track & Trace software) for pharmaceutical manufacturers and contract packagers. It connects Carton Printing System (CPS) machine modules that print data matrix codes and tamper-evident seals with CPI Track & Trace software from Bosch," Rauschnabel says (Figure 3).

Dave Harty, head of professional services, Americas, with Adents (East Windsor, N.J.; www.adents.com), adds that a large percentage of the recalls that occur in the pharmaceutical market deal with packaging issues. "Wrong label stock, incorrect inserts, poor readability and dynamically printed data are all issues," he says. "A great deal of effort is currently being spent on 'right the first time' (RFT) programs and, correspondingly, an increase in using various technologies to reduce human error and increase the verification of the packaging processes to reduce the packaging issues and move the company closer to RFT goals," Harty says (Figure 4).

To do so, Harty says, there has been an increase in cost-effective vision inspection technologies that provide the ability to inspect every individual item for a multitude of conditions that currently are managed by human beings and are subject to a great deal of error and incorrect evaluation. The ability to add these

Adents

FIGURE 4. A great deal of effort is being spent on "right the first time" programs and, correspondingly, an increase in using various technologies to reduce human error and increase the verification of the packaging processes to reduce the packaging issues

To respond to the growing demand for safety in food packaging, Linde developed the in-line MAPAX leak-detection system for foods packaged with tray sealers or thermoforming machines. It tests packages in-line and can achieve 100% sampling at speeds up to 120 packages per minute. It works by adding a small volume of hydrogen as an indicator to the modified atmosphere mixture at the package sealing stage. The sensor checks for the gas after the sealed packages travel into the leak-detection unit. If the non-destructive test detects a leak, a visual alarm signals so issues can be immediately resolved and a defective item can be removed from the production line with minimal interruption to the process flow.

additional inspections and apply the same evaluation in a repeatable and consistent manner is helping to reduce packaging issues.

"We are seeing a combination of advances in both the equipment itself, as in machines and devices, and the software applications that interoperate with the equipment becoming far more sophisticated, especially in the areas of event notification and connectivity options," he says. "Internet connectivity and email support are two of the technologies that have become standard functionality instead of optional or add-on functionality."

Food processors also have to deal with industry-specific regulations, such as the Food Safety & Modernization Act of 2011, which shifted the focus from contamination response to prevention, and necessitated the development of more sophisticated inspection equipment. "In-line testing on the front end became a goal because it has advantages over previously existing leak-detection methods, such as immersion testing, which tests packages at random intervals or a determined sampling number," says Erik Fihlman, program manager for bakery, prepared foods and seafood for Linde LLC (Bridgewater, N.J.; www.lindeus.com). "Previous methods were effective for that particular package, but by the time you noticed a leak on that package, you'd already produced *X* number of packages that may or may not also have leaks, so processors had to either discharge, re-package or re-check all the packages that came between the two checkpoints."

"Food safety is a major risk. While the ultimate goal is to protect the consumer, processors also know that one incident can stop a plant or close a business," says Fihlman. "Processors have hazard analysis plans in place to mitigate those risks, and this type of equipment makes it easier for the processor to check off that box. They can be more secure that the product leaving the plant and going to the consumer is in the state it's expected to be in."

Reliability and efficiency

For chemical processors, efficient packaging of their palletized goods is a deciding competitive factor, creating the need for efficient palletizing solutions, which are often part of an overall packaging solution designed specifically to enhance efficiency. "Some of the crucial factors related to palletizing are transport security, anti-theft protection and display characteristics of the packaged goods, as well as weatherproofing for outside storage," says Gregor Baumeister, manager of palletizing and packaging systems division at The Beumer Group (Aarhus N, Denmark; www.beumergroup.com). "Further key factors are process efficiency and cost reduction, as well as the system output."

Baumeister says the system solution often provides a seamless approach to efficiency. "The customer gets from us a fully functioning system with all mechanical and electrical components, as well as the associated software program. We often see software-based strategies as being the key to increasing performance or energy efficiency," he says.

A typical, sophisticated system solution might work as follows: Bulk materials pass from the silo along a conveyor section to the form-fill-seal system. The bagging machine is fitted with an integral high-precision weigher, which ensures the accuracy of the bag weights, then high-performance palletizers stack the bags quickly and accurately on pallets.

"Because efficient palletizing is such an important characteristic for chemical processors, our palletizers can be fitted with a rotary clamp or double belt turning device, which moves the filled bags into the required position," explains Baumeister. "Even bags filled with granulate can be gently palletized, remaining dimensionally stable when stacked. Customers can use the high-performance packaging system in the stretch hood series to secure the load. The film fits snuggly over each product on the pallet, ensuring safe transport and good load stability. These filling, palletizing and packaging systems help fulfill the complex requirements of chemical processors," he says (Figure 5).

Built-in intelligence and connectivity combined with application technologies are also helping to enhance the performance of packaging equipment.

For example, the Beumer Group has developed the Beumer Overall Operation Monitoring application that enables staff to maintain an overview of all the relevant parameters of their packaging line on their mobile devices at any time. "The application shows the status quo of availability, performance and quality levels, as well as the energy and compressed air consumption. This ensures efficient operation of all systems. The program can be adapted to customer-specific requirements," says Baumeister.

Pineberry Manufacturing Inc. (On-

The Beumer Group

FIGURE 5. The high-performance packaging system in Beumer's stretch hood series can be used to secure the load. The film fits snugly over each product on the pallet, ensuring safe transport and good load stability

Pineberry Manufacturing

FIGURE 6. Open Source friction feeders from Pineberry Manufacturing include a PLC touchscreen with smartphone app capabilities

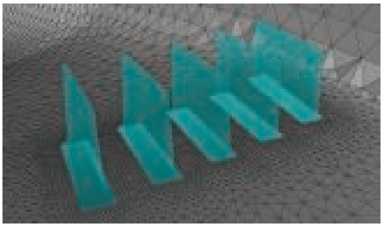
tario, Canada; www.pineberryinc.com) also upped the intelligence and added an app to enhance the reliability of its equipment. "All of our friction feeders used to come equipped with a control box, but now most of our Open Source friction feeders include a PLC touchscreen with smartphone app capabilities (Figure 6)," says Chris Pereira, marketing manager with Pineberry Manufacturing. "The app can report realtime machine data on both the machine's PLC and the smartphone app. In addition, increased use of automation greatly reduces bottlenecks, human errors and label costs, improves order fulfillment and will help meet new packaging demand requirements, moving forward."

With the goals of product quality, efficiency and reliability in mind, today's packaging equipment and systems are being developed with innovative solutions that help processors meet all these product packaging requirements. ■

Joy LePree

Focus on software for chemical process applications

Pointwise



Endress+Hauser

Honeywell Process Solutions

Upgraded meshing capabilities improves CFD modeling output

Ensuring optimal output from computational fluid dynamics (CFD) software requires reliable, high-fidelity meshes to be created for the complex geometries that are being modeled. The latest version of this company's CFD mesh-generation software, Version 18.0 R3, includes more than two dozen new features and advanced graphics capabilities (photo), and it is said to improve the resolution of details at very small scales on complex geometries, thereby improving the visualization of results. The company's software generates structured, unstructured, overset and hybrid meshes, and it interfaces seamlessly with CFD solvers from a range of vendors, as well as many neutral formats. — *Pointwise, Inc., Fort Worth, Tex.*
www.pointwise.com

Enterprise solution helps to manage risk and compliance

The ProcessMAP Incident Management enterprise solution helps companies manage data and processes in order to improve performance related to environmental health and safety, risk management and other considerations. It streamlines reporting and tracking of worker injuries and illness, environmental issues, property damage and vehicular incidents. By creating enterprise-wide access to a web-based platform and improving organizational alignments, the program utilizes "big data" analytics to create actionable insights to improve safety efficiencies and mitigate risks. The program can also be used to centralize safety programs — that are often manual and fragmented — into a single centralized, cloud-based platform that streamlines data and provides realtime visibility to relevant metrics. The program also allows users to identify the most frequent types of incidents, to support ongoing-improvement initiatives. — *ProcessMAP, Sunrise, Fla.*
www.processmap.com

This software improves tank-inventory management

SupplyCare 3.0, software for tank-inventory management (photo) provides a complete overview of levels and product inventory in a company's tanks and silos worldwide. Recent enhancements include hardware and software options that allow level, flow and pressure data to be displayed at a desk or on a handheld device, regardless of location. The SupplyCare Enterprise system's advanced inventory-managaement tools improve forecasting, reporting, stock analysis and more. Operators and administrators can access the application via a web browser from their desks or handheld devices, such as smartphones and tablets. SupplyCare can create reports in various formats, including Excel, PDF, CSV and XML, and data can be shared with, and used by, other systems and computing platforms. — *Endress+Hauser, Greenwood, Ind.*
www.us.endress.com

Process-modeling tools help to optimize engineering workflow

The process modeling capabilities that are enabled by this software allow engineers to create a number of steady-state, dynamic models for plant and control design and optimization, hazard and operability (HAZOP), and safety-system studies, performance monitoring, troubleshooting, business planning and asset management. UniSim Design Suite, Release 450 (photo) is the newest version of the company's process-modeling software. The many process-design and simulation tools that are included in this software portfolio are designed to help operators in the oil-and-gas, petroleum-refining, petrochemical, chemical and power industries to increase their engineering effectiveness and

Note: For more information, circle the 3-digit number on p. 62, or use the website designation.

optimize their process designs, says the company. — *Honeywell Process Solutions, Houston*
www.honeywellprocess.com

Improve simulation with this mathematical solver

Comsol Multiphysics and Comsol Server software, Version 5.3, is a mathematical tool that benefits simulation specialists with faster modelling capabilities, development tools and solvers. Its many user-driven features are said to improve app development and enable shorter solution time, thereby increasing research and development throughput across many industries. In many cases, users will experience a speedup of ten times or more in software responsiveness, such as in pre-processing tasks for handling models with several thousand boundaries and domains, says the company. For instance, Version 5.3 provides the boundary element method (BEM), which can improve the modeling of electrostatics and corrosion effects. Users handling large CFD models also benefit from the new algebraic multigrid (AMG) solver, which requires only a single mesh level and is now the default option for many fluid-flow and transport-phenomena interfaces. — *Comsol, Burlington, Mass.*
www.comsol.com

Data-analytics software helps make sense of raw data

The latest version of KnoweldgeNetAnalytics (also known as KNet Analytics; photo) provides advanced capabilities in capturing, storing, processing, analyzing and visualizing raw data, to benefit operations and manufacturing intelligence, "big data" analytics, plant automation, command-and-control systems. Among its varied aspects, the KNet Analytics new alarm-analytics module combines several data-analytics and advanced techniques to allow users to extract knowledge from alarm databases and go beyond classical alarm management/ The added capabilities provide better auditing, to allow users to pinpoint nuisance alarms, identify alarm correcations and clustiering (to remove redundant alarms and reduce alarm floods), use pattern recognition to predict the future behavior of alarms (to increase reliability and safety), and correlate alarms with process data for better troubleshooting and root-cause analysis. — *Integration Objects, Houston*
www.integrationobjects.com

Improved software benefits these precision balances

This company's XPE precision laboratory balances, combined with its proprietary LabX software (photo), are designed to enhance laboratory bench operations and scaled-up manufacturing processes. Specifically, the ability to record before-and-after weight values against unique sample-identification information, and all calculations are performed and results recorded automatically, eliminating manual transcription and assuring traceability. Meanwhile, as instrument-control software, LabX runs on the instruments and supports the laboratory technician using a touchscreen that provides complete user guidance to both operate the instrument and follow standard operating procedures. — *Mettler Toledo AG, Greifenssee, Switzerland*
www.mt.com

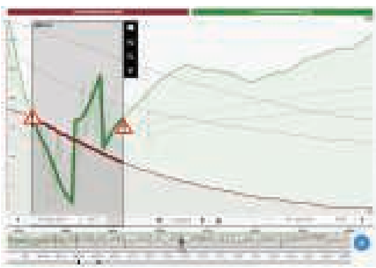
Software improves pattern recognition, trend analysis

TrendMiner 2.0 is the latest version of this company's predictive-analytics software (photo), which is designed to improve collaboration for achieving better process-performance optimization. Its high-performance analytics engine for process-data capture in time series helps process engineers and operators easily identify trends in their processes to optimize both efficiency and quality. With improved "self-service" analytics capabilities, and using multivariate pattern recognition, the software allows users to question the data directly without requiring help from a data scientist, says the company. It also provides improved self-service monitoring. For instance, users can easily define a "golden batch" and fingerprint it, then set up multivariate alarms with predefined boundaries. The software monitors these fingerprints and sends notifications to the engineering and control room staff in the event of deviation or issues. — *TrendMiner, Houston*
www.trendminer.com ■

Suzanne Shelley

Integration Objects

Mettler Toledo



TrendMiner

GE Water & Process Technologies

Pfeiffer Vacuum

Water Planet

MSA Safety

A highly adaptable reverse osmosis system

The PROflex reverse osmosis (RO) system (photo) features a new online product configurator that allows users to select the exact flowrate required by an application from a range of PROflex RO products. The recently redesigned system has a smaller footprint than previous models and boasts several design features that enable systems to be designed for specific flow, flux and water requirements. Ten base configurations are available with up to 72 8-in. elements. Various pump sizes are available, along with many options for instrumentation and programmable logic controllers (PLC). Simplified piping streamlines cleaning and modifications, and the pump has been placed in front of the skid for easier maintenance access.— *GE Water & Process Technologies, Trevose, Pa.*
www.gewater.com

Rotary vane pumps for critical applications

The DuoLine two-stage high-performance rotary vane pumps (photo) cover all low- and medium-vacuum applications, achieving pumping speeds of 1.25 to 11 m^3/h. Applications range from mass spectrometry or optical coating to critical industrial applications, such as drying processes, metallurgical processes or resin casting systems. The company has significantly improved the water-vapor tolerance of the pumps by using an optimized gas-ballast system. The DuoLine has a long service life and a pumping speed that is independent of the type of gas. Because of their compact design and optimized cooling, the pumps are very well suited for system integration. — *Pfeiffer Vacuum GmbH, Aßlar, Germany*
www.pfeiffer-vacuum.com

These ultrafiltration membranes offer extreme hydrophilicity

The PolyCera Hydro (photo) is a new ultrafiltration membrane for drinking water applications where total suspended solids (TSS), turbidity and pathogen removal are of concern. PolyCera Hydro can be used in place of conventional polymeric membranes for drinking-water treatment in high-purity and ultrapure water filtration, as well as in surface water, seawater and groundwater treatment facilities. While PolyCera Hydro is designed for drinking-water applications, the PolyCera Titan model is available for industrial wastewater treatment. All PolyCera membranes offer extreme hydrophilicity, which leads to improved fouling resistance and ease of cleaning, says the manufacturer. The membranes are stable in extreme pH conditions, high temperatures and oxidants, and are highly tolerant to oil and solvents. — *Water Planet, Los Angeles, Calif.*
www.waterplanet.com

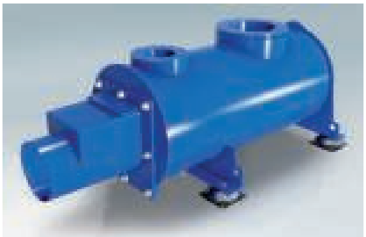
This gas monitor has a dual-sensor design

The Ultima X5000 gas monitor (photo) is a replacement for this company's Ultima X device, eliminating the need for specialized setup tools or a separate controller. The Ultima X5000 can be operated from the two touch buttons on its OLED display or wirelessly via a Bluetooth-enabled smartphone or tablet from up to 75 ft away. Shown prominently on the display screen are a gas reading gage, progress bar, operational status, maintenance alerts and alarms. With the ability to connect two sensor inputs into one transmitter, wiring costs and installation time are significantly reduced. Equipped with this company's XCell electrochemical sensors, catalytic bead sensors or point infrared (IR) sensors, the monitor detects any two combinations of combustible gases; H_2S or CO in multiple ranges; and 0–25% O_2. — *MSA Safety Inc., Cranberry Township, Pa.*
www.msasafety.com

This software suite integrates analytics and machine learning

Asset Performance Management (APM) is a complete software suite for site, process and equipment-performance management that combines process modeling with realtime big data and machine-learning solutions. The APM suite is designed to increase asset uptime, improve reliability, extend the life of equipment and achieve optimal process performance system-wide. The integrated suite of APM analytics provides pre-

Aerzener Maschinenfabrik



DuPont Protection Solutions

GEMÜ Gebr. Müller Apparatebau

Kaman Precision Products

scriptive guidance to address multiple levels of asset performance, including: site-wide risk analysis via Fidelis Reliability software; process analytics to assess the root causes of process disruptions, predict future occurrences and prescribe actions to avoid them; and equipment performance analytics via Mtell software to predict when failures will occur. Also included in APM are pre-packaged analytics for column troubleshooting that use ensemble modeling to provide operational guidance, as well as advanced multivariate analytics for process and batch monitoring.— *Aspen Technology, Inc., Bedford, Mass.*
www.aspentech.com

A reactive silencer keeps these compressors quiet

The sound waves from the discharge side of this company's Delta Screw compressor can reach 170–190 dB. Therefore, a downstream silencer is obligatory, as with other compressors. In conventional dissipative silencers, the high frequencies of the sound waves lead to considerable vibration forces, which have a damaging effect on the piping and the insulating material. This so-called microfriction wears out the filter material over time and can damage even stainless steel in the long run, thereby reducing the effectiveness of the silencer. The erosion of fine particles can also contaminate the process air. To eliminate these challenges, the company has patented a reactive silencer (photo). The special piping system generates a defined counter-noise, which superimposes the sound waves with a certain delay and thus neutralizes them. The company now also equips its direct-drive screw compressors with reactive silencers. — *Aerzener Maschinenfabrik GmbH, Aerzen, Germany*
www.aerzen.com

New PPE garment protects against both chemicals and fire

Tychem 2000 SFR (photo) is a new protective garment designed for use in operations where dual protection against chemical and fire hazard threats is paramount to worker safety. Tychem 2000 SFR provides a barrier against a range of inorganic acids and bases, plus industrial cleaning chemicals, as well as particulate matter. In the event of a flash fire, Tychem 2000 SFR garments will not ignite, and therefore do not contribute to additional burn injury if the wearer uses appropriate flame-resistant (FR) personal protective equipment (PPE). If a fire hazard exists, Tychem 2000 SFR garments must be worn over an appropriate FR garment, along with other PPE that protects workers' faces, hands and feet. Special features of the Tychem 2000 SFR coverall include: a respirator-fit hood; chin flap with double-sided adhesive tape for secure placement; and elastic at the waist and tunneled elastic at the hood, wrists and ankles for improved fit. — *DuPont Protection Solutions, Richmond, Va.*
personalprotection.dupont.com

An efficient motorized actuator for globe and diaphragm valves

The new eSyDrive motorized actuator (photo) is designed on the basis of the hollow shaft principle in conjunction with technology that does not use brushes or sensors. The self-locking actuator also offers a high level of reproducibility for positioning and is therefore particularly suitable for use in precise control applications. The Ethernet-based eSy web interface, in conjunction with an integrated web server, enables the exchange of parameterization and diagnostics data and the networking of several devices. Depending on the size, the actuator has an actuating speed of between 2 and 6 mm/s. — *GEMÜ Gebr. Müller Apparatebau GmbH & Co. KG, Ingelfingen, Germany*
www.gemu-group.com

Self-tuning transducer senses position, displacement or proximity

The new digiVIT digital variable impedance transducer for linear position, displacement and proximity sensing (photo) features a self-tuning bridge that can work with nearly any sensor and any conductive target. The transducer also features simple pushbutton calibration, temperature compensation and zeroing. Its embedded intelligence ensures that all functions are accessible, with no need to connect to a PC to download a configuration file when changing sensors or performing high-level calibrations. The operating tem-

perature range for digiVIT devices is 32 to 122°F, with recommended storage temperatures ranging from –4 to 158°F. — *Kaman Precision Products, Inc., Middletown, Conn.*
www.kamansensors.com

Precise measurement and control of gases

The new generation of high-precision mass flowmeters (MFM) and controllers (MFC) for gases (photo) feature an integrated Industrial Ethernet switch and support all standard Industrial Ethernet protocols. This allows the devices to be flexibly integrated in existing systems. The two versions (Type 8741 and 8745) cover a broad measurement and control range. They are used at high and low pressures, as well as for low and high flowrates. Typical applications for mass flowmeters and controllers are in the areas of metal, glass or ceramic processing, coating technology or in the production of foams. MFCs/MFMs are also used in fermenters and water treatment systems. The Type 8741 handles nominal flowrates of up to 150 L/min, while the Type 8745 devices permit a maximum of 2,500 L/min (both relative to N_2). — *Bürkert Fluid Control Systems, Ingelfingen, Germany*
www.burkert.com

Bürkert Fluid Control Systems

Detect the presence of steam and water in boilers and drums

The Mobrey Hydratect 2462 detection system (photo) is used in applications where the detection of water or steam is vital, such as boilers, steam drums and steam-line drain pots. A functional safety assessment carried out by Exida determined that the Mobrey Hydratect system meets the requirements of safety integrity level (SIL) 3. With capabilities to operate at up to 300 bars and 560°C, Hydratect is intended as a replacement for conventional float switches, and consists of a compact twin-channel electronic unit connected to a pair of electrodes. Each channel gives independent indications of the presence of water or steam that are said to be more reliable than those obtained with electro-mechanical devices. By installing the electrodes in vessels or steam lines and measuring the resistance, the presence of water can be detected, allowing appropriate safety measures to be taken. — *Emerson, St. Louis, Mo*.
www.emerson.com

Emerson

A new probe for measuring hydrogen peroxide vapor

The HPP272 probe for the measurement of vaporized hydrogen peroxide (photo) can measure not only the hydrogen peroxide content (ppm) of bio-decontamination processes, but also temperature, relative humidity (RH, only water vapor) and relative saturation (RS, whole gas mixture). The probe's sensor has a purge function that helps maintain measurement accuracy between calibrations and extends the operating life of the probe. This function heats the sensor rapidly to remove possible impurities left in the sensor's polymer films. According to the manufacturer, the HPP272 probes require calibration only once a year and very little maintenance. The sensor's intelligent measurement algorithm and heating function ensure water cannot condense on the sensor. This keeps measurement data reliable, even in extremely high humidities. — *Vaisala Oyj, Helsinki, Finland*
www.vaisala.com/h2o2

Vaisala

A 'single-pot' system for the food industry

Mixing, granulating, coating, drying and heating and cooling can be performed in this company's "single-pot" process developed for the food industry. The process performs chemical reactions or mechanical product treatment in one machine; several process steps can take place without having to isolate the intermediate products. Depending on the application, all reactants can be added into the machine right at the beginning of the process or sequentially, as required. The system consists of a mixer composed of a horizontal, cylindrical drum equipped with a main mixing shaft fitted with a shovel that generates a mechanical fluid bed by rotating. Vacuum drying can then be performed in the same machine, saving time and treating the product with care. — *Gebr. Lödige Maschinenbau GmbH, Paderborn, Germany*
www.loedige.de ■
Mary Page Bailey and Gerald Ondrey

Lödige Maschinenbau

Zeolites

Department Editor: Scott Jenkins

The physical properties of zeolites make them extremely important in many industrial processes. This one-page reference provides information on the structure and chemistry of zeolites that allows their use in the chemical process industries (CPI).

Zeolite structure

Zeolites are a class of hydrated aluminum silicates made up of silica and alumina tetrahedra (SiO_4 and AlO_4 linked in a tetrahedral configuration). The linked tetrahedra form complex three-dimensional structures with large, cage-like cavities and channels (Figure 1). Zeolites have open, non-dense structures — 20–50% of a zeolite's volume is void space. Zeolites' uniform framework of pores can be exploited to control chemical reactions by adsorbing reactant molecules within the zeolite pores. Certain reaction pathways will be favored based on the shape and chemical composition of the zeolite pores.

There are 45 types of naturally occurring zeolites, but their structures and properties are limited from an industrial perspective. Most industrial uses employ one or more of the close to 200 synthetic zeolites that currently exist. The International Zeolite Association (www.iza-online.org) Structure Commission assigns a three-letter code for each class of zeolites, corresponding to its three-dimensional crystal structure.

Synthetic zeolites allow control of a wider range of properties, including Si-to-Al ratio, pore size and geometry, and the ability to incorporate metals and other elements into the active sites. Most synthetic zeolites are made using a process of slow crystallization of a silica-alumina gel in the presence of alkalis and organic templates. Many possible zeolite structures are theorized.

Major industrial uses

Zeolites are widely used in the CPI; the majority in the following three general areas:

Catalysis. Because zeolites are cation exchangers, it is possible to introduce a variety of cations with different catalytic properties into the zeolite's crystal structure. Simultaneously, their rigid pore geometry serves as a steric influence on reactions, where the pore size and shape controls the access of reactants and products. By controlling the pore size and architecture, engineers can suppress formation of undesired products, for example. Zeolites serve as catalysts for many important reactions involving organic molecules in the petroleum refining and petrochemical sectors (see Table 1).

Adsorption and separation. Zeolites' porous crystalline structure can be exploited as a molecular sieve, where molecules with certain properties are preferentially adsorbed.

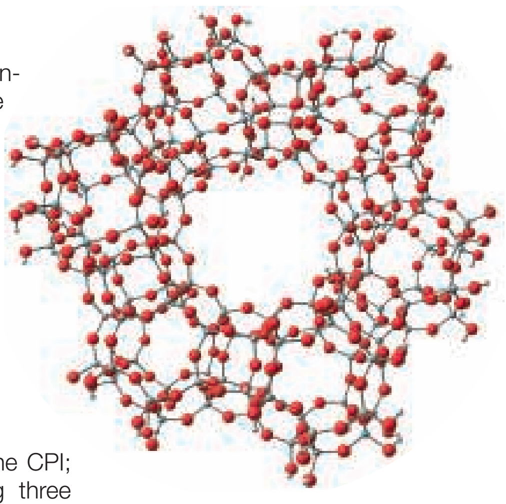


FIGURE 1. The linked silica and alumina tetrahedra of zeolites create cage-like cavities and channels that can be exploited to control chemical reactions

Zeolites can be designed to separate molecules according to differences in size, shape and polarity, making them useful as dessicants and in gas separation.

Ion exchange. Hydrated cations within the zeolite pores are bound loosely to the zeolite framework, and can exchange with other cations in aqueous media. This ability makes zeolites useful as industrial water-softeners, where sodium and potassium ions in the zeolite are exchanged for calcium and magnesium ions in the water. Also, zeolites can be used to remove radioactive or toxic heavy-metal cations from liquid nuclear waste and groundwater, respectively.

Catalysis chemistry

In addition to cations, zeolites can have protons bound into their framework. This molecular structure gives rise to high acidity, which can be useful in many key organic reactions. Protons can act as Brønsted acids (proton donors) in reactions with hydrocarbons that form carbocations, for example. ■

TABLE 1. SAMPLE ZEOLITE-CATALYZED REACTIONS IN THE PETROCHEMICAL INDUSTRY

Process	Zeolite platform/carrier catalyst type	Reaction
Fluid catalytic cracking (FCC) of crude petroleum fractions, such as vacuum gas oil (VGO)	Zeolite Y (IZA code FAU). ZSM-5 (IZA code MFI)	High-molecular-weight hydrocarbons are broken into C5 to C8 hydrocarbons, as well as C3 and C4 olefins, such as propylene
Isomerization of light gasoline	Acidic zeolite with noble metal	Conversion of straight-chain alkanes to branched-chain isomers to achieve higher octane numbers
Hydrocracking of heavy petroleum distillates	Zeolites X and Y (IZA code FAU)	Converts poor-quality feeds into gasoline and kerosene
Catalytic dewaxing	ZSM-5 (framework code MFI) and others	Selectively hydro-isomerizes or cracks straight-chain and slightly branched paraffins. Used to improve cold-flow properties of diesel fuel and lubricant oils
Alkylation of benzene	HZSM-5 (ion-exchange sites occupied by H^+)	Combining ethylene with benzene to create ethylbenzene for styrene and other purposes
Disproportionation of toluene	ZSM-5; others may be used also	Transfers methyl group to create more valuable *para*-xylene and benzene from toluene
Isomerization of xylenes	ZSM-5	Creates *para*- and *ortho*-xylene from *meta*-xylene, a less valuable product

Selected references

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Urea Production from NH_3 via a Self-Stripping Process

By Intratec Solutions

Urea is a nitrogenous compound consisting of a carbonyl group attached to two amine groups. Urea plays an important role in many biological processes, but is also an important material in synthesis (for example, resins and plastics), as well as in fertilizers and animal feed.

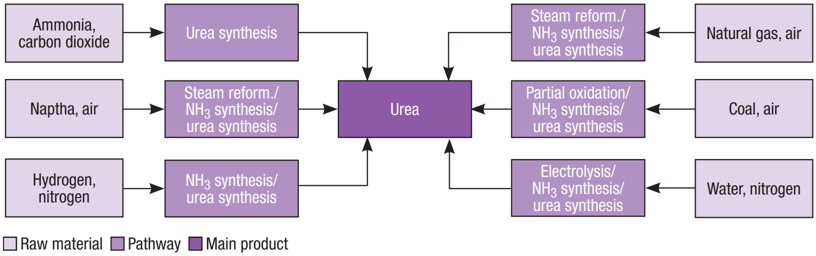

FIGURE 2. Several possible production pathways exist for urea

The process

The process described is similar to Saipem's (formerly Snamprogetti) self-stripping process, based on formation of ammonium carbamate from liquid NH_3 and gaseous CO_2, followed by dehydration of the ammonium carbamate to urea. Figure 1 presents a simplified flow diagram of this process.

Reaction. Initially, CO_2 and a liquid mixture of ammonia and carbamate, recovered downstream, are fed to the urea reactor, part of the high-pressure synthesis loop. Here, the ammonia and the CO_2 react, yielding ammonium carbamate and urea.

Stripping. The reactor effluent, containing carbamate, is fed to a falling-film stripper, where excess NH_3 strips out the carbamate from the effluent. The off-gas from the stripper is absorbed in a liquid carbamate stream recovered downstream, and fed to a kettle-type boiler to be condensed and recycled to the reactor. The heat exchanged is used to produce steam.

Carbamate decomposition. The urea solution is directed to two successive decomposers for the removal of residual carbamate and CO_2. After decomposition of carbamate and evaporation of ammonia, a urea solution, substantially free of carbamate, is obtained. The off-gas from the decomposers is rectified in a medium-pressure absorber, from which gaseous ammonia is obtained as the top product and a liquid ammonium carbamate stream is obtained as bottom product. The ammonia is condensed, mixed with fresh ammonia and routed to urea synthesis, while the ammonium carbamate is directed to the condenser.

Urea concentration. At this point, the urea-water mixture is concentrated in a two-stage evaporator, forming a urea melt suitable for prilling (pelletizing). The vapor obtained is condensed and directed to a condensate treatment unit. The treatment consists of stripping and hydrolysis steps, and the condensate obtained is used as process water and boiler feed water, while the off-gas, containing ammonia and CO_2, is recycled to urea synthesis.

Finishing. Here, the urea melt is sprayed at the top of a prilling tower, forming spheroidal urea particles (called prills) which are packed in bags and stored.

Urea production pathways

Urea was first produced in 1828 from ammonia and cyanic acid in aqueous solution. Modern commercial urea manufacture occurs exclusively from NH_3 and CO_2, in such a way that different production routes are related to different sources of those materials. Figure 2 shows the different pathways by which urea is produced.

Economic performance

The total operating cost (raw materials, utilities, fixed costs and depreciation costs) estimated to produce urea is about $220 per ton of urea. The analysis is based on data from the second quarter of 2013 from a plant with capacity to produce 1.3 million metric tons of urea per year. It was assumed that the plant is integrated to an ammonia unit that supplies ammonia, at its cost of production.

This column is based on "Prilled Urea from Ammonia via Self-Stripping Process – Cost Analysis," a report published by Intratec. It can be found at: www.intratec.us/analysis/urea-production-cost. ■

Edited by Scott Jenkins

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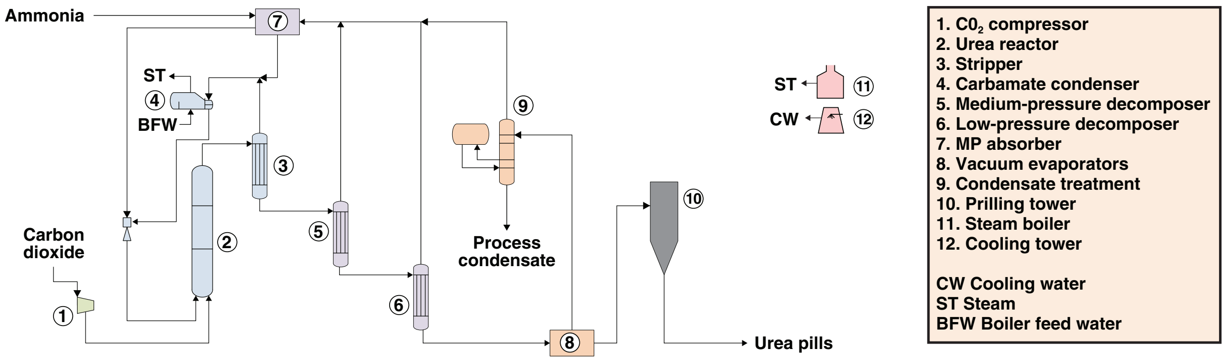

FIGURE 1. This diagram shows prilled urea production from ammonia via a self-stripping process

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Activated Carbon: Fundamentals and New Applications

Activated carbon sorbents are important tools in water purification and air-pollution control. This article provides information on the fundamentals of this diverse sorbent and on new applications for which it is being employed

Ken Koehlert
Cabot Corp.

IN BRIEF

ACTIVATED CARBON BASICS

RAW MATERIALS

ACTIVATION PROCESSES

POST-PROCESSING

ADSORPTION FUNDAMENTALS

FACTORS AFFECTING PERFORMANCE

APPLICATION TYPES

BIOGAS PURIFICATION

SEDIMENT REMEDIATION

Global sustainability trends are creating increased demand for purification of air and water, as well as more environmentally friendly process alternatives. Activated carbon (AC) sorbents play important roles in applications throughout the chemical process industries (CPI). These range from traditional applications, such as municipal water purification and fluegas treatment, to cutting-edge applications, such as adsorbed natural gas storage and double-layer capacitors.

In this article we review the basics of activated carbon, as well as the link between activated carbon properties and adsorption performance. In addition, the article provides an overview of two emerging applications for activated carbon sorbents — biogas purification and sediment remediation.

Cabot

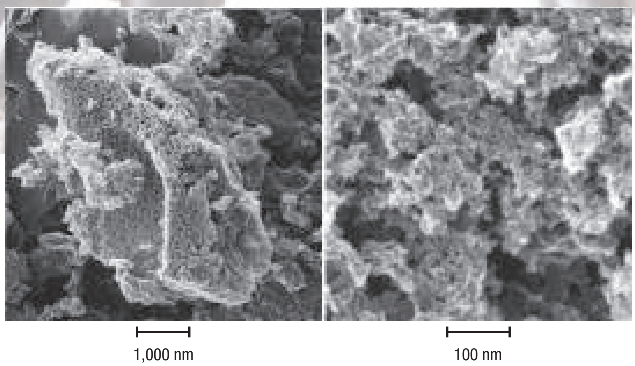

FIGURE 1. These images from a helium-ion microscope show the pore structure of lignite-based activated carbon

Activated carbon basics

Activated carbon is a highly porous, high-surface-area adsorptive material with a largely amorphous structure. It is composed primarily of aromatic configurations of carbon atoms joined by random cross-linkages. Activated carbon differs from another form of carbon — graphite — in that activated carbon has sheets or groups of atoms that are stacked unevenly in a disorganized manner. The degree of order varies based on the starting raw material and thermal history. Graphitic platelets in steam-activated coal are somewhat ordered, while more amorphous aromatic structures are found in chemically activated wood.

Randomized bonding creates a highly porous structure with numerous cracks, crevices and voids between the carbon layers. Activated carbon's molecular size porosity and the resulting enormous internal surface area make this material extremely effective for adsorbing a wide range of impurities from liquids and gases. To provide some perspective for the internal surface area of activated carbon, the annual activated carbon production of the author's employer has a surface area nearly equal to the total land area on Earth (148 million km^2). Figure 1 shows two micrographs of the internal structure of steam-activated lignite.

Activated carbon sorbents are tailored for specific applications mainly based on pore size and pore volume requirements. Porosity and other parameters are controlled by the following: 1) raw material selection; 2) activation process conditions; and 3) post-processing steps. Depending on the application, activated carbon may be in the form of powder (PAC), granule (GAC) or extrudate (EAC). All three forms are available in a range of particle sizes.

Raw materials

Almost any carbon-containing material can be used to produce activated carbon. In practice, economics and target product properties are the determining factors in the selection of raw materials. The base raw material has a significant impact on the final product properties, including pore size distribution and volume, hardness and purity. Most commercial activated carbons are manufactured from the following raw materials:

- Coal (anthracite, bituminous, subbituminous, lignite)
- Coconut shell
- Wood

Some types of activated carbon are produced from less conventional raw materials, such as peat, olive stones, fruit pits, petroleum coke, pitch, synthetic polymers, scrap tires and waste cellulose materials.

Raw materials may undergo pre-processing steps to control size, form and other properties. They may be crushed, milled, briquetted or mixed with binders and extruded prior to activation.

Activation processes

Activated carbons are manufactured via one of two processes: steam activation at high temperature or chemical activation using a strong dehydrating agent.

Steam activation is the most commonly used method for activated carbon production. It is performed in rotary kilns, shaft kilns, multi-hearth furnaces or fluidized beds, and proceeds through the following steps:

Drying. Activated carbon raw materials in commercial use contain residual moisture that must be removed before activation can take place.

Devolatilization. Volatile organic compounds (VOCs) are formed by cracking reactions in the raw material at temperatures between 100 and 400°C.

Charring. Higher-molecular-weight organic materials are converted to a carbonaceous char residue at temperatures of 400–600°C. At this point, incipient porosity and increased internal surface area begin to form.

Activation. Activation is generally conducted in a steam atmosphere at temperatures between 700 and 1,050°C, depending on the pore structure of the carbon being produced. The desired reaction is shown in Equation (1).

$$C + H_2O \rightarrow CO + H_2 \qquad (\mathbf{1})$$

This reaction gasifies portions of the solid carbon to create pore volume. Typically, about half of the carbonaceous char material entering the activation step will be reacted away to create the desired internal pore structure. The diagrams in Figure 2 depict the development of porosity during steam activation.

Chemical activation is used to produce carbons with pore structures and compositions that are somewhat different from those in steam-activated carbons. For example, chemically activated wood has higher mesoporosity and higher oxygen content than a steam-activated carbon. The chemical activation process consists of mixing raw biomass with a strong dehydrating agent and heating to about 400 to 700°C. The dehydrating agent (typically phosphoric acid or zinc chloride) extracts the moisture from the raw material and fixes the volatile component of the biomass while the activation occurs. The degree of activation is determined by the ratio of raw material to dehydrating agent and by the heating time and temperature. After activation, the product is extracted to yield a highly porous activated carbon product and the the dehydrating agent is recovered.

Chemical activation with potassium hydroxide is of great recent interest because it can produce highly microporous carbons with specific surface areas at or beyond the theoretical value for graphene (about 2,600 m^2/g).

Post-processing

Following activation, activated carbon sorbents may undergo a series of post-processing steps, including the following:

Cabot

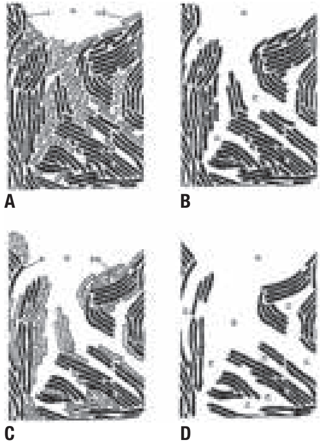

FIGURE 2. This series of diagrams illustrates pore development during steam activation

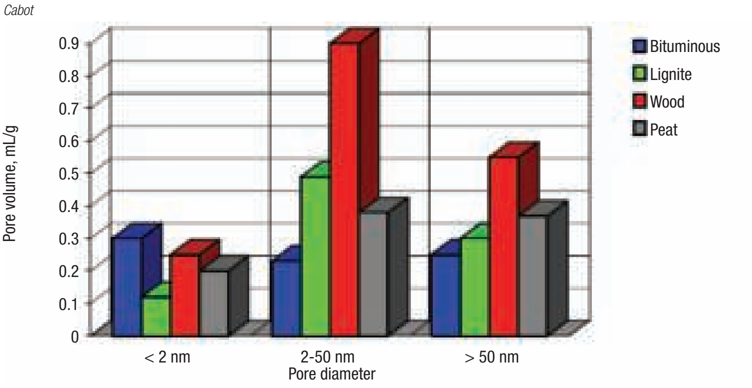

FIGURE 3. The distribution of pore volumes differs depending on the starting material for the activated carbon

Washing. Activated carbon may be acid-washed to reduce ash content and remove soluble impurities, such as iron. Varying levels of increased purity are required for some applications, including double-layer capacitors, pharmaceuticals and food and beverages.

Sizing. Granular products may be sieved to specific particle size ranges. Common mesh-size specifications range from 20 x 40 to 4 x 8 mesh (approximately 0.4 mm x 0.8 mm to 2 mm x 5 mm). Extrudates are produced with diameters ranging from 0.8 to 5 mm and length-to-diameter ratios between about 1:1 to 4:1. Granule and extrudate sizes are specified to balance mass transfer and pressure drop. Powder products are often ground in roller, hammer or jet mills to achieve a target particle-size distribution (PSD), often specified by the terms d5, d50 and d90, which are measures of particle diameters. D50 (median particle size) can range from 5 to about 20 micrometers (μm). Smaller particles improve mass transport, but can lead to filterability challenges. Tight control of PSD can optimize the balance.

Shaping. Powdered activated carbons may be formulated with binders and shaped into cylinders, tubes, honeycombs and other extruded forms to optimize surface-to-volume ratio and pressure drop for various applications. Granules and extrudates may also be formed into filter blocks and plates using polymeric binders.

Impregnation. Some contaminants, such as formaldehyde, elemental mercury and hydrogen sulfide are not adsorbed on activated carbon. Chemical impregnation can add functionality to the carbon sorbent to catalyze a reaction or promote chemisorption. Activated carbon manufacturers add functionality for a range of applications. Silver is commonly used to disinfect water. A more specialized example is impregnation with metal salts and amines for military gasmasks. On a larger scale, impregnation is used to promote the oxidation of mercury in coal-fired utility fluegas applications. Products for enhanced sulfur removal are impregnated with potassium iodide or sodium hydroxide. Another example of impregnation by end-users is the deposition of precious metals on activated carbon to form heterogeneous catalysts.

Re-activation. Some granular and extruded products can be re-activated and recycled after use to minimize cost and environmental impact. In this process, spent carbon loaded with organic contaminants is thermally treated in a process similar to steam activation. Reactivation desorbs and destroys volatile contaminants and restores much of the original pore volume and adsorptive capacity. Typical product loss during reactivation is 5–15%, requiring makeup with virgin material.

Adsorption fundamentals

Activated carbon sorbents remove low concentrations of chemicals (adsorbates) from a fluid (liquid or gas) by adsorption, the process of accumulation of materials onto a solid surface. Adsorption occurs within the activated carbon pore structure by two distinct mechanisms: physical and chemical adsorption.

Physical adsorption. Molecules are attached to the carbon surface by van der Waals attractive forces. These intermolecular forces are very weak and diminish with increasing distance between the carbon surface and the adsorbate molecule. Because the weak attractive forces are greatly dependent on distance, physical adsorption occurs primarily within pores that have a radius only a few times greater than the molecular diameter of the adsorbed molecule. Pores that are smaller than the size of the impurity molecule are inaccessible and do not participate in the adsorption process. Pores that are significantly larger than the adsorbate molecule are not as effective at adsorption because the attractive force diminishes as the distance between the pore surface and the adsorbate is increased.

Adsorption occurs after the impurity molecule has diffused into the carbon

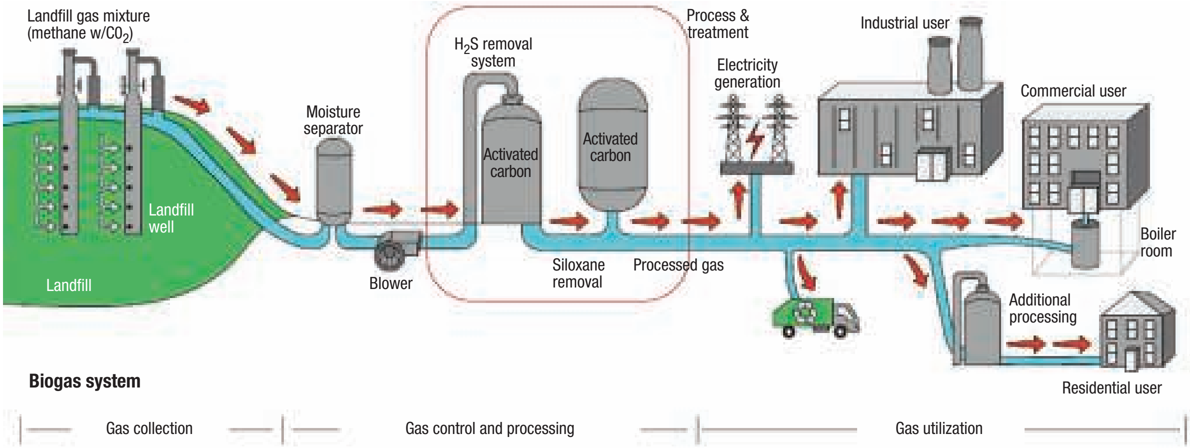

FIGURE 4. This schematic diagram shows the collection, purification and use of biogas from a landfill site

pore structure to an adsorption site. The process is diffusion-rate-limited and the large pores play a role in transporting adsorbate to the adsorption sites. Physical adsorption is an equilibrium process and is very dependent on the concentration of the adsorbate in the solution.

The relationship between the amount of adsorbate on the surface versus that in the solution is described by the adsorption isotherm. The Freundlich adsorption isotherm, shown below in Equation (2), is commonly used to empirically define this relationship.

$$C_{carbon} = k_f C_{water}^{1/n} \quad (2)$$

Where:

C_{carbon} = concentration of adsorbate adsorbed on carbon

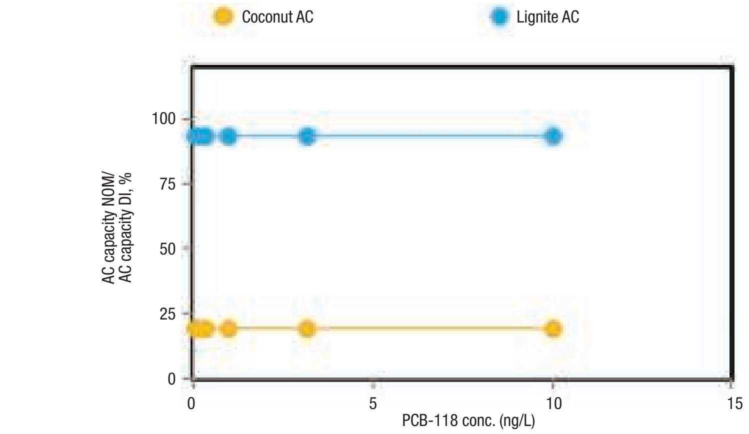

FIGURE 5. This diagram shows a comparison of lignite- and coconut-based activated carbon performance with 50 mg/L natural organic material (NOM)

C_{water} = equilibrium concentration of adsorbate in solution

K_f and n are constants for a given HOC and carbon at room temperature

The partition coefficient (C_{carbon} / C_{water}) can be calculated from Freundlich equation at a given equilibrium concentration.

If a single compound is being adsorbed by activated carbon, all pores of a suitable size are available for adsorption and the amount of material adsorbed is the maximum achievable by the particular carbon.

If several adsorbate molecules are present, there can be competition for the adsorption sites. In that situation, the larger impurity molecules will block some of the smaller pores. This may reduce the carbon's ability to adsorb the smaller-sized adsorbates.

Chemical adsorption. Chemical adsorption refers to the direct reaction of the adsorbed molecule with an active site on the carbon surface. As a result of the reaction, a chemical bond is formed between the adsorbate and the carbon surface. The active sites on the carbon surface involved in chemisorption are mainly functional groups that contain oxygen and alter the electron balance of the carbon surface. If the molecule being adsorbed is chemically bound to the carbon surface (shared electrons), the process is termed chemisorption.

If the adsorbed molecule resides only temporarily on the carbon surface, picks up an electron, and then leaves the carbon surface, the process is described as catalytic conversion. This is the mechanism responsible for the dechlorination reaction used by bottlers to convert free chlorine in water to chlorides.

Factors affecting performance

Factors that affect the performance of activated carbons can come from the specifics of the application, or from the activated carbon itself.

Application-related factors. Several factors can aid or hinder adsorption. The principal factor is the molecular size of the compound being adsorbed. Activated carbon adsorption increases as the size of the molecule being adsorbed increases. Certain types of functional groups on the impurity molecule can also affect its adsorbability.

Because the physical adsorption process is an equilibrium reaction, the concentration of the molecule to be adsorbed strongly affects the amount adsorbed, as described by the adsorption isotherm. The solubility of the adsorbed compound is also important, with lower solubility resulting in greater adsorption.

Adsorption rate increases with temperature. However, desorption rate also increases with temperature and it is not possible to predict the net effect in liquid-phase applications. The principal reason for adsorbing at elevated temperatures in the liquid phase is to lower viscosity and increase diffusion rate. In gas-phase applications, adsorption always decreases with higher temperature.

Activated-carbon-related factors. In adsorption applications, the most critical performance parameter is the distribution of pore size and volume. Since adsorption occurs almost exclusively in pores just a few times larger than the adsorbate molecule, it is the pore volume within this size range that determines adsorption capacity. The highly porous nature of activated carbon gives rise to surface areas as large as 3,000 m^2/g.

Pore sizes are classified as micro-, meso- or macropores, according to the conventions of the International Union of Pure and Applied Chemisty (IUPAC; iupac.org). Micropores with widths less than 2 nm are useful for adsorbing small molecules, especially in vapor applications. Mesopores, ranging in width from 2 to 50 nm, are in the right size range to adsorb many contaminant materials. Macropores greater than 50 nm in width have minimal adsorption capacity, but are critical in determining adsorption kinetics within the particle. The larger pores provide transport paths for molecules to diffuse into the mesopores and micropores, where adsorption takes place. Figure 3 compares the pore distribution of four different activated carbons from a variety of raw materials and activation processes.

Surface area can be determined by nitrogen adsorption using the BET (Brunauer, Emmet, Teller) method. Pore size distribution can be quantified by examining the adsorption and desorption of nitrogen, carbon dioxide and other adsorbates. Mercury porosimetry is well suited to measure macropore and large mesopore volume. However, it is more common and convenient to measure and rank activated carbon performance using specific adsorbates that mimic the application. Examples include iodine adsorption to assess small pore capacity and dye molecule adsorption (methylene blue, bromophenol blue, and so on) to assess medium-sized pores. In some cases, the characterization test is directly related to the final application, as in the case of molasses decolorizing efficiency as a predictor of performance in sugar applications, and butane working capacity as a performance metric for carbons used to control automobile gasoline vapor emissions.

Particle size and distribution impact performance in both PAC and GAC applications. For PAC, size and size distribution correlate to mass-transfer resistance and filterability. In batch applications, a fine particle size provides rapid adsorption, but also a high pressure drop and slow filtration when removing the sorbent. The best balance of performance is often found by narrowing the size distribution. In GAC and extrudate packed-bed applications, size is again related to mass-transfer resistance and pressure drop.

Durability is of particular concern for GAC and EAC forms. Particles must be able to resist damage and fines formation during transport, column loading and use — especially if the application involves column backwashing. Activated carbons for gold extraction have some of the most stringent durability requirements. Durable particles are also required to minimize losses during re-activation.

High purity is critical in some applications. Food, beverage and potable water applications require low levels of extractables. Pharmaceutical activated carbons must have ultra-high purity and full traceability. Emerging uses in double-layer capacitors and other electrochemical applications depend on high purity for extended cycle life.

Application types

Activated carbon sorbents are used in two broad application classes: vapor and liquid purification. Within each class are examples of two types of fluid-sorbent contacting. These are PAC dosing and GAC/EAC packed columns. Beyond purification, activated carbons are used in a number of specialized applications.

In PAC dosing systems, activated carbon particles are injected into the contaminated fluid, dispersed within the fluid for an appropriate contact time, and then removed by sedimentation or filtration. PAC dosing may be used in batch or continuous injection systems. PAC contact times range from 0.05 to 2 seconds in gas-phase systems and 1 to 60 minutes in liquid-phase batch applications. In municipal water treatment, PAC may be added continuously as a slurry or powder and then can be removed by flocculation, sedimentation and filtration. In coal-fired utility mercury removal, PAC is injected into the fluegas through a distribution lance and removed in the electrostatic precipitator or fabric filter.

In packed-bed systems, fluid flows through a static bed of GAC or EAC. As the contaminant concentration in the fluid decreases, the loading on the carbon increases, creating a concentration gradient along the column. The mass-transfer zone is defined by the gradient between the inlet concentration existing in the fully loaded bed and the outlet concentration. Breakthrough occurs when the mass-transfer zone travels to the exit of the column. Packed-bed systems are sized based on either calculated or experimentally determined isotherms, contact time based on estimated or measured kinetics and mass transfer, and pressure drop requirements.

Vapor-phase purification applications cover a wide range of contaminant molecules from mercury to volatile organic materials. Some specific examples include gasoline vapor in automobile evaporative-loss-control devices, mercury in coal-fired utility fluegas and dioxin in incinerator offgas. Another vapor-phase application is pressure- or temperature-swing adsorption for solvent recovery and hydrogen purification. Impregnated carbons are used in military gasmasks and industrial respirators to protect personnel from toxic gases. An emerging application in this area — removal of hydrogen sulfide and siloxanes from biogas — is highlighted below.

One of the most effective technologies for high-performance impurity removal in biogas is a two-step treatment with activated carbon

Activated carbon sorbents are used to purify a wide range of liquid systems, including potable water, wastewater, industrial process water, chemicals, pharmaceuticals, foods and beverages. Removal of taste and odor contaminants and harmful pollutants from potable water is one of the main purification applications. Activated carbon is used to remove precious metal catalysts after synthesis of pharmaceutical active ingredients. Liquid sugar decolorization is one of the earliest activated carbon applications and remains important today. Activated carbon is used to remove undesirable taste compounds and color precursors from processed fruit juices. Color removal from natural-gas liquids is a more recent application. Activated carbon application in sediment remediation is covered in more detail below.

Non-purification applications of activated carbon include gold recovery from cyanide leaching solutions, storage of gases, such as hydrogen and methane, and electrodes for double-layer capacitors and catalysts.

Biogas purification

Biogas is an environmentally friendly and sustainable fuel derived from the breakdown of organic matter. It is typically produced at landfills, wastewater treatment facilities, or through anaerobic digestion using animal manure or vegetation. The main constituents of biogas are methane and carbon dioxide, however, it also contains undesirable impurities like hydrogen sulfide (H_2S), siloxanes and VOCs. These unwanted impurities are present in low concentrations, but must be removed to reduce combustion equipment damage and downtime, to ensure emission targets are met, and to meet gas-purity specifications. After purification, the biogas can either be sent to an engine to generate power, sold into the natural gas grid or sold as a transportation fuel in the form of biomethane. Figure 4 shows where activated carbon adsorption is used in a typical biogas system.

One of the most effective technologies for high-performance impurity removal in biogas is a two-step treatment with activated carbon. For optimal performance, an operator will first direct a humid gas through an activated carbon bed where H_2S is reduced to elemental sulfur by a catalytic process. After H_2S removal, the gas is dried and sent to a separate activated carbon bed, where siloxane and VOC impurities are removed by physical adsorption.

H_2S purification. H_2S is a hazardous chemical compound present in biogas. Biogas producers need to remove H_2S because it is poisonous, corrosive, flammable and malodorous. Traditionally, biological scrubbers, iron-oxide-based media, or impregnated activated carbons have been used for H_2S removal in biogas. All technologies are capable of removing H_2S; however, none of these technologies has been optimized specifically for biogas. Biological scrubbers are very effective at removing high concentrations of H_2S, but can be difficult to operate and capital-intensive to install. Iron oxide media are low-priced, but generally demonstrate very low removal efficiency. Iron oxide media are also notorious for bricking (bridging between particles, forming lumps), which leads to costly and time-intensive removal efforts. Chemically impregnated activated carbon has a higher loading efficiency, but can be quite expensive. Impregnated carbons can also pose safety challenges, as they may cause bed fires due to an exothermic reaction with H_2S.

Many operators today are focusing on total cost of ownership and are choosing a media or engineered solution that offers the lowest cost per mass of H_2S removed. In making this calculation, the operator considers capital investment for each technology, followed by analysis of long-term operating costs. For media-based solutions, they must consider the amount of media needed to fill the vessel, the operating time until media saturation, the cost and time associated with media changeouts, and ultimately, how the downtime impacts the ability to process gas. It is important to consider total lifecycle cost in developing activated carbons for biogas H_2S removal.

Siloxanes and VOC purification. Siloxanes are a group of synthetic compounds used in the manufacture of personal hygiene, healthcare and industrial products. Disposal of these products creates the risk of siloxane impurities in biogas, posing significant risks depending on the final application. In combustion engines, boilers, turbines and fuel cells, siloxanes can form silica that causes damage, destruction and reduced operating efficiency. Siloxane damage leads to higher operational costs and can seriously impact biogas upgrading and even prevent sales of contaminated biogas.

VOCs are impurities often found in biogas derived from agriculture, landfills and wastewater-treatment facilities. Depending on the application, VOCs can be viewed either as beneficial or detrimental to the quality of the gas. If the biogas is sent for combustion, the VOCs are often considered a beneficial high-Btu additive. When biogas is further upgraded to biomethane, VOCs must be removed to prevent significant damage to membranes and to limit emissions of sulfur oxides and nitrogen oxides. Pipeline gas has strict limits on VOC concentration.

Activated carbon has traditionally been used for siloxane and VOC removal, as it is effective at physically removing both compounds. For dedicated siloxane removal, users often opt for temperature-swing adsorption (TSA) using an activated-carbon bed as a polishing step. The decision to use activated carbon versus TSA typically comes down to operating conditions and costs. TSA systems have relatively high upfront capital costs and also use significant amounts of gas for regeneration. If an operator is pulling from a gas-limited source, they will likely prefer using activated carbon only. TSA units are also known to struggle with removing some lower-molecular-weight siloxanes, which means that they often require activated carbon polishing vessels to remove all siloxane compounds. High concentrations of siloxane in a biogas can lead to high operational costs to replace a standard activated carbon because much of the carbon pore volume is spent removing different families of compounds from the gas. Specifically designed surface modifications to standard activated carbon can allow the preferential adsorbtion of siloxanes over VOCs. This results in significantly better siloxane loading capacity versus standard activated carbon products. Since this type of modified product does not require a TSA unit to achieve high performance, it is a way that processors could avoid the need to invest in an expensive system upfront, but still realize long-term savings.

Biogas is one of the more challenging gas-purification applications. Depending on the source, the amount and the speciation of impurities is constantly variable. When deciding which adsorption technology to deploy, an operator must consider many factors to determine the highest-performance and most cost-effective solution for their site.

Sediment remediation

Sediments accumulated on the bottom of waterbodies are sinks for toxic, bio-accumulative chemicals that can be transferred to invertebrates and fish via food webs. Increasingly, remediation practitioners are turning to in-situ treatment of contaminated sediments to reduce the ecological and human-health risks posed by contaminants. This is mainly because conventional technologies (such as dredging and conventional sand capping) have not always demonstrated risk reduction. A new approach of in-situ sediment treatment via contaminant sequestration involves placing activated carbon amendments on contaminated sediments. In this application, activated carbon is used to adsorb HOCs, such as polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyl (PCBs) from sediment pore water. One challenge in this application is interference from natural organic matter (NOM). Large organic molecules present in the water matrix, such as humic and fulvic acids, can cause blockage of the activated carbon pore structure, leading to reduced adsorption capacity for target contaminants. Highly microporous carbons are particularly prone to blockage. Activated carbon with a tailored blend of mesoporosity and microporosity is required for resistance to NOM and removal of target contaminants.

Increasingly, remediation practitioners are turning to in-situ treatment of contaminated sediments to reduce human health and ecological risks

Lignite-derived, activated carbon grades now exist specifically for removing PCBs, PAHs, dioxins and furans in contaminated sediments. Activated carbons developed for this application have an optimal pore size distribution that is designed to be highly effective for the removal of these compounds in the presence of NOM concentrations typical in sediment pore water. This broad pore-size distribution is critical for high performance, as NOM can partially or completely block the adsorptive capacity of more microporous carbons. Figure 5 compares microporous coconut AC and lignite AC with tailored porosity in removal of PCB-118. The chart shows the ratio of PCB removal in water with 50 mg/L NOM to removal in distilled water and clearly demonstrates lignite's resistance to pore blockage.

Activated carbon amendments are applied to the sediment either by direct mixing, as a component in a geotextile mat, or by incorporating it into a cap that creates a physical and adsorptive barrier between the contaminated sediment and water. The cap consists of sand or aggregate and carbon can be added as GAC or as a PAC coating applied to the surface of the aggregate.

In order to design reactive caps using activated carbon, engineering firms frequently use the CAPSIM model, developed by professor Danny Reible of Texas Tech University (Lubbock, Tex.; www.ttu.edu). To assess and approve a specific activated carbon grade in a reactive cap, engineering firms require specific activated-carbon performance data, namely the partition coefficient, which can be calculated from a Freundlich adsorption isotherm equation at a given equilibrium concentration of the contaminant in pore water.

The author's employer has generated partition coefficients for a wide range of PAH and PCB contaminants for activated carbon products in this area. These data, combined with knowledge of site conditions, enables the design of reactive caps using the CAPSIM model. Using the right activated carbon amendment and cap design can provide in-situ sediment remediation solutions that prevent breakthrough from contaminated sediments for 100 years or more.

Summary remarks

Activated carbon is a sorbent with wide-ranging uses in the purification of vapor and liquid systems, as well as specialized uses in fuel storage, catalysis and electrochemistry. Activated carbon can be tailored for specific applications by a combination of raw material selection, activation process conditions and post-processing, including shaping and chemical impregnation. Adsorption performance is driven by pore size and volume distribution, and other factors, such as durability and particle size, influence the choice of activated carbon for a specific application. Activated carbon can be used in liquid or vapor applications in either PAC or GAC/EAC form. Biogas purification and sediment remediation are two recent applications that highlight the versatility of activated carbon sorbents for purification applications. ■

Edited by Scott Jenkins

Author

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Rupture Discs: Effectively Minimize Leaks and Emissions

When installing rupture discs, there are several mechanical and operational considerations for reducing the likelihood of leaks and fugitive emissions

Alan Wilson
Mike Quimby
Oseco

IN BRIEF

Overpressure relief systems consisting of rupture discs and relief valves are vital for preventing damage and injury within chemical processing plants and petroleum refineries. These systems experience leakage or fugitive-emission problems when installed, maintained or specified improperly. Consequences for such leakage issues may include plugging, corrosion, product loss and contamination. More serious consequences may also occur, including endangering employees and the public, fines or cleanup fees issued by regulatory agencies and lost production due to unplanned shutdowns.

Rupture discs do a good job of minimizing leaks through the planned overpressure relief path. However, preventing leakage to the atmosphere between the rupture disc and holder requires proper device specification and correct installation. There is also a need for careful inspection, proper cleaning and regular maintenance of components. Understanding the various rupture disc technologies, assembly types and sealing mechanisms employed will help users prevent leakage and fugitive emissions in their plant's overpressure relief systems.

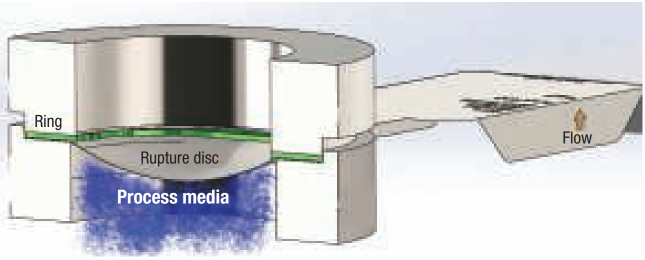

FIGURE 1. Holder design is important for ensuring that rupture discs are installed in the proper orientation

Rupture discs under relief valves

The most common application for rupture discs is the isolation of pressure relief valves. Pressure relief valves use springs or other mechanisms to apply pressure to sealing surfaces to contain the process media. Overpressure events force the sealing surfaces to separate, releasing process fluids until the pressure drops below the set pressure. At this point, the sealing surfaces close to contain the remaining pressure. Relief valves used without rupture discs often leak, especially if operating pressures are too close to the set pressure of the relief valve. Leakage from a relief valve results in product loss, corrosion of sealing surfaces, sticking and additional wear on the valve. The added stresses on the relief valve will commonly lead to system shutdowns for maintenance at more frequent intervals. Unplanned shutdowns for maintenance prove very costly to plants and can be avoided by placing rupture discs under pressure relief valves.

Rupture discs open much faster than relief valves, create a leak-tight seal, and may be readily manufactured in a variety of materials for compatibility with most process media. They are quicker and more cost-effective to produce from expensive, corrosion-resistant alloys compared to relief valves. Once activated, the rupture disc remains open until replaced. Placing a rupture disc on the upstream side of a relief valve is an effective way for plants to utilize the advantages provided by each technology.

Rupture discs help maintain the sealing surfaces of a relief valve and keep the valve in pristine condition. In the event of an overpressure situation, the relief valve will reliably reseat itself, without risk of product buildup or corrosion. Utilizing rupture discs as a first line of defense will help extend the life of the relief valve, increase the time between required maintenance intervals and reduce overall costs related to the overpressure relief systems.

Pairing the two technologies for overpressure relief raises an additional layer of consideration to ensure the desired result is achieved. According to American Society of Mechanical Engineers (ASME; New York, N.Y.; www.asme.org) Boiler and Pressure Vessel Code (BPVC) XIII-1 UG-127(a) (3) (-b) (-4), the space between the rupture disc and the relief valve must be monitored for changes in pressure. Rupture discs are differential pressure devices, meaning that the burst pressure of the disc is dependent on the pressure both upstream and downstream of the rupture disc. If a rupture disc develops a small leak due to mishandling, corrosion or other damage, the pressure builds up between the rupture disc and the relief valve. A pressure buildup downstream of the rupture disc effectively raises the actual burst pressure of the disc. This additional pressure causes the disc to activate at a pressure higher than the intended burst pressure of the disc. As a result, it is critical to monitor this space for pressure, which is typically accomplished by using a pressure gage or a monitored pressure switch.

Rupture disc technologies

Before evaluating possible causes of leaks related to rupture discs, it is important to understand the various assembly types and the limitations of their technologies. Rupture discs are available in many different types. However, this article limits its consideration to "insert type" assemblies intended to be mounted between piping flanges. Most rupture discs can be described as one of four types: pre-bulged, composite, forward-acting scored and reverse-buckling scored. Manufacturers usually make one or more versions of each type, and may use different names or model numbers to describe them. For more information on rupture disc types and maximizing their operating performance, see Modern Rupture Discs Support Increased Capacity, *Chem. Eng.*, June 2016, pp. 38–43.

Pre-bulged and composite types of forward-acting rupture discs were the industry standard for decades. Though they can be effective solutions for simple applications, they offer little flexibility for improving system performance. For example, neither is ideal for relief valve isolation. Both designs are susceptible to fragmentation, making them unsuitable for use under pressure relief valves. Fragmenting rupture discs can damage or get stuck in the sealing surfaces of pressure relief valves. This prevents proper closure when the overpressure event subsides. These disc types are also subject to lower operating ratios, fatigue in cyclic environments and require additional vacuum supports in the presence of negative pressures. Both designs are still manufactured today for use in angle-seat holders and more modern flat-seat holders.

Rupture disc performance was elevated with the advent of scoring technologies paired with the annealing of the metal to control the tensile strength and minimize stresses from cold-working. These processes yielded two new families of rupture discs: the forward-acting scored and the reverse-buckling scored discs. Both disc types outperform their pre-bulged and composite counterparts in terms of higher operating ratios, non-fragmenting designs and precision of activation pressures.

While users will pay higher prices for these more advanced technologies, they will benefit from increased performance and productivity through reduced downtime and the ability to operate at higher pressures. They will also find opportunities to save money by consolidating applications and reducing inventory levels. Because both scored-disc types perform well in demanding applications, replacement costs and scheduled maintenance intervals may be reduced. The consolidation of inventory paired with higher-performing discs helps users realize much larger savings throughout the plant. To reap these benefits, supervisors must provide training and continued education for all staff involved in specifying and installing these devices.

FIGURE 2. Leaks can occur through the relief system if rupture discs become compromised

Holder sealing technologies

Angle-seat holders have long been used in the rupture disc industry. The angled surface creates a partial cone shape, which wedges together the surfaces of the inlet and the outlet. Rupture discs designed for these holders have matching angle-seat geometry. Angle-seat holders are prone to pinching through the components of the rupture disc. Application of excess torque alters the geometry of holders, deforming them to a point where they are unable to properly seal. Most rupture disc suppliers discourage the use of angle-seat holders in favor of flat-seat holders or alternative designs.

Flat-seat holders come in two main varieties, designed for either forward-acting or reverse-buckling discs. Both are designed to accommodate corresponding rupture disc designs and help to seat the disc in its proper orientation. Each manufacturer has proprietary holder designs intended to work only with its corresponding rupture disc. The seating surfaces are perpendicular to the flow path and parallel to one another (Figure 1). Each disc manufacturer also has a slightly different method for creating a concentrated force through the use of a reduced contact area. Often called a nubbin

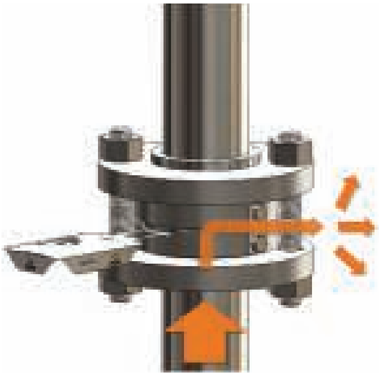

FIGURE 3. Leaks can occur outside of the planned flow path in rupture disc systems if all components are not correctly installed

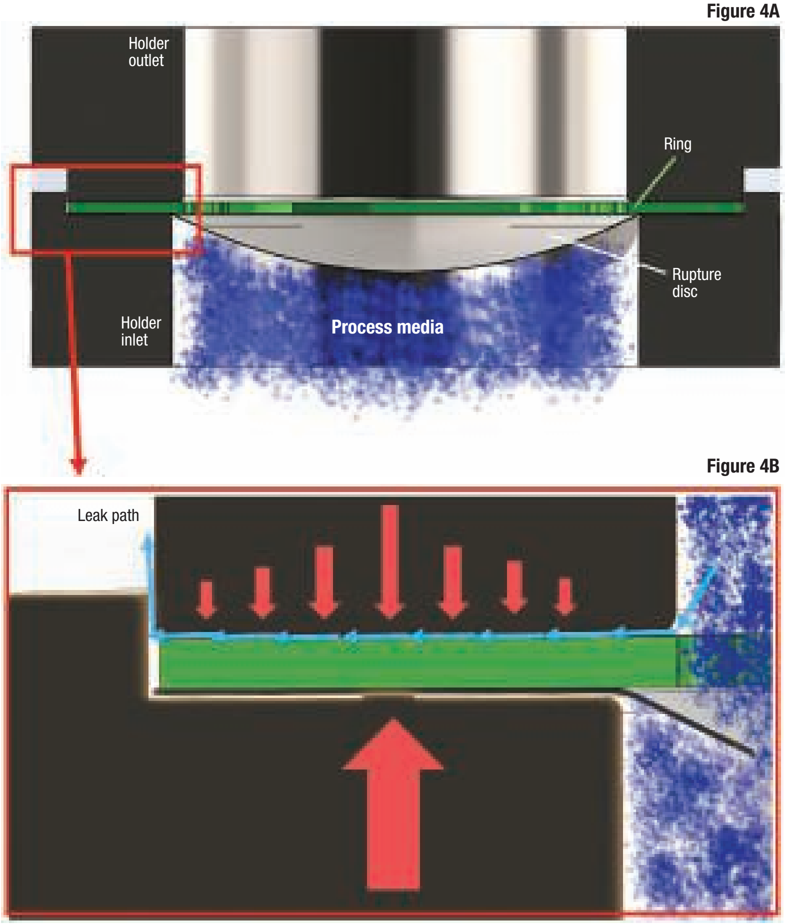

FIGURE 4. Shown in Figure 4A is a rupture disc with a ring on the outlet. The concentration of stress on the ring (Figure 4B) can make the system more susceptible to leaks outside the planned flow path

seal, this designed force creates a leak-tight seal between the inlet side of the holder and the process side of the rupture disc. This arrangement makes the rupture disc and holder much less prone to damage when torque forces exceeding the holder's individual torque specifications are applied to the flanges. It also minimizes the damaging effects of uneven torque application. Today, nearly all high-performance scored rupture discs are mounted in flat-seat holders.

Pre-torque holders are flat-seat holders that allow the user to install the rupture disc into the holder and apply torque to cap screws in a controlled environment. Applying controlled amounts of torque to the preload cap screws better ensures proper disc seating before the holder is installed between the actual piping flanges. Many facilities use this type of holder so that a trained individual can clean and inspect the holder for damage that may cause leakage. The installer can then verify that the correct disc is being installed and that the disc is in its proper orientation. Proper torque is then evenly applied to the preload cap screws to ensure the disc-to-holder seal is achieved. The pre-torqued disc and holder assembly can then be passed to an individual with less training and expertise to install it into the piping system. This type of assembly may help reduce installation and leakage issues when combined with proper training and maintenance.

Usually, the technologies described previously provide satisfactory performance under the right circumstances. These assemblies must be carefully cleaned and inspected by well-trained individuals. They must then be installed in properly aligned piping precisely according to all installation procedures.

A new technology

One-piece units are the most recent evolution in rupture-disc assembly technology. They are a variation of flat-seat holders, and are beginning to emerge in chemical processing plants. These units consist of a rupture disc and holder combination that is typically assembled at the factory utilizing high-integrity welds. Companies that have experienced problems involving overpressure-relief systems understand the value derived from a sealed rupture disc and holder assembly. One-piece units eliminate installation errors due to improper torquing, mismatched discs and holders, improper disc orientation, inadequate cleaning, corrosion damage, holder wear and lack of inspection. A hermetically sealed assembly keeps the process in the piping, effectively reducing a potential leak point in the system. This technology eliminates the need for installers to determine if holders are too worn, corroded or damaged to be reused. The use of one-piece units ensures there will be no unplanned downtime resulting from leakage related to a damaged holder. Finally, the simplified installation process leads to faster installation times and less required training for maintenance teams.

Leaks through the relief system

As discussed, rupture discs are typically mounted in holders designed for a specific brand and type of rupture disc. These holders are designed in such a way that, barring any specification or installation errors, the only way for a rupture disc to leak through the system is if the disc has been compromised (Figure 2). This can happen in several ways, as described in the following sections.

Corrosion. Rupture discs are manufactured from thin material. End users usually have several disc materials from which they may choose. Material choice is sometimes dependent upon the type of assembly selected. Plants can upgrade from 316 stainless steel to a more corrosion-resistant alloy, such as Hastelloy, without significant increases in cost. Fluoropolymer liners or coatings provide additional protection in many cases. No matter the assembly type in question, proper material specification is critical for corrosive media applications.

Improper installation. Installing a rupture disc in the wrong holder or in the wrong orientation can damage the rupture disc. This can either alter the burst pressure or create potential leak paths. Newer, high-performance rupture discs are sometimes designed to be fail-safe, meaning that in the event of improper installation, the disc will burst at or below the marked burst pressure. Discs not considered to be fail-safe may open at a burst pressure several times the marked burst pressure when installed upside down. The results from an overpressure situation in the above described scenario could prove catastrophic for a plant. Forcing the rupture disc and holder between flanges that have not been opened far enough, or that are misaligned, can create similar issues. Therefore, the selection of a rupture disc assembly that reduces the risk of simple installation errors and requires less training for personnel needs to be considered.

Excess or uneven torque. Excess torque on the holder or flanges can damage the seating surfaces of a rupture disc holder, making it difficult to seal when the rupture disc is replaced. Excess torque can also lead to splitting, wrinkling, tearing or other damage to rupture-disc sealing components in multilayer or composite designs in particular. Angle-seat rupture discs and holders are especially prone to permanent damage due to excess torque. Proper training and tools help prevent this kind of error, as well as emerging assembly types, such as a one-piece unit, that make it impossible for torquing force to damage the rupture disc within its assembly.

Fatigue. Forward-acting rupture discs that have endured multiple excursions close to the set burst pressure can experience fatigue. Over time, this reduces the amount of pressure required to create an opening in the disc, usually resulting in a crack or split rather than a full opening. Such a crack in the disc creates a leak through the system and may cause the disc to activate at a lower burst pressure. This phenomenon, often identified as premature failure, can prove very deceptive to personnel, especially when operating pressures are not continually monitored. High-performance, scored reverse-buckling rupture discs are much more resistant to premature failure due to fatigue.

Physical damage prior to installation. Rupture discs are precision devices made of carefully selected and crafted materials. The materials of construction can be very thin — sometimes just 0.001 in. thick. It is very important that rupture discs are transported and handled carefully to prevent dents, scratches and holes. If a rupture disc is damaged, it should be discarded rather than repaired. Pushing a dent out of a rupture disc, for example, does not restore it to its pre-damaged condition. Most rupture discs can be provided in individual boxes to encourage installation crews to leave them in protective packaging until installation. Employee training in the proper handling of discs will greatly reduce these errors. The specification of fully integrated one-piece assemblies may also offer additional protection for the rupture disc as it is carried by an installer to the application site.

Physical damage due to debris. Rust, grit and debris that may be present on flanges and in piping can cause leaks in a system. Remember, some of the rupture disc components can be as thin as 0.001 in. Compressing a piece of sand or grit into those thin materials can easily create a leak path. Hermetically sealed, fully integrated, one-piece disc assemblies may help to reduce this risk. They eliminate the need to remove the rupture disc from its holder, a process that may allow debris to interfere with the sealing mechanisms.

Leaks outside the planned flow path

In certain situations, rupture discs can leak outside of the planned flow path (Figure 3). Most of the causes listed in the previous sections can lead to process media leaking between the inlet of the holder and the process side of the rupture disc. There is also an additional cause for leakage that is rarely considered.

Some rupture discs are designed and manufactured to include a thicker ring that is spot-welded to the outlet side of the rupture disc. This ring is usually constructed of 0.010- to 0.125-in. thick metal. There are several purposes for this ring. First, it makes the disc more resistant to damage from handling. Another benefit of the ring is its ability to eliminate fragmentation. These rings provide a concentration of stress, or teeth, to assist in the opening of a reverse-buckling scored rupture disc. Finally, the ring provides a more robust attachment point for identification tags.

Placing the heavy ring on the outlet side of the rupture disc ensures that the reduced area on the holder inlet seat seals tightly against the sealing member of the rupture disc prior to the disc opening. However, if the disc is operating under a relief valve and the system remains under pressure after the rupture disc relieves, process media may leak in between the thicker ring and the holder outlet (Figure 4). The thicker ring spreads the sealing force applied by the mating flanges over a larger area on the outlet side of the disc. This leaves the outlet side of the assembly more vulnerable to leakage. Manufacturers offer holders with bite seals on both the inlet and outlet; however, the results are not 100% reliable. The only certain way to prevent this source of leakage is with a one-piece unit offering a hermetic seal.

Importance of training

Rupture disc installation training is vital to preventing leaks and other types of failures. Some rupture disc manufacturers will set up training at users' facilities to cover the basics of installation. One may want to design their own basic training course to focus on situations specific to the facility. Relevant topics may include the following:

- Application types, including primary relief, secondary relief or relief-valve isolation
- Rupture disc designs, such as forward-acting, reverse-buckling or flat
- Installation preparation, focusing on safety, cleanliness and holder inspection
- Installing a disc in a holder, considering orientation and side lugs
- Installing rupture disc and holder between flanges, focusing on gaskets and proper torque

When properly specified and installed, rupture discs are a reliable means of protecting plants from overpressure situations and preventing leakage associated with pressure relief valves. Understanding the advantages of the various rupture disc assembly types is vital for preventing leaks while providing overpressure relief. With proper specification, training and maintenance, many of the technologies described in this article can provide satisfactory results. If the application is challenging, or if maintenance, inspection and training levels are not maintained, selecting a more advanced technology, such as a one-piece unit, can offset these deficits. Rupture disc manufacturers can help sort through performance issues and often have training programs available for maintenance staff and installers.

Most importantly, engineering teams can assist with proper specification. Plants with well-trained employees utilizing the best rupture disc technologies will experience peak system performance with minimal downtime related to process leakage. Ongoing innovation efforts in device design continue to increase the reliability, performance and ease of use of these vital safety components. ■

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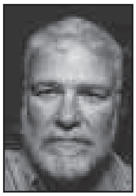
Authors



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Proper Sizing and Installation for Steam System Safety Valves

Successful operation of safety valves in steam systems requires careful adherence to established industry standards for installation and design

Kelly Paffel
Inveno Engineering, LLC

IN BRIEF

One of the most critical safety devices in a steam system is the safety valve. Figure 1 is an illustration of a typical safety valve, and Figure 2 shows a valve in context on a steam line. Safety valves protect personnel, equipment and property from potentially dangerous high temperatures and forces caused by excessive steam pressure in the steam system.

Steam safety valves are required by industry standards, as well as insurance and corporate mandates. Therefore, it is important that the safety valve be properly sized and installed to meet all code requirements.

The code that establishes the requirements for steam safety valves is written by the American Society of Mechanical Engineers (ASME; New York, N.Y.; www.asme.org). ASME, through its committees, has published and continues to update the Boiler and Pressure Vessel Codes (BPVC) for safety valves. It is the responsibility of plant personnel — primarily the plant's steam team — to know which codes apply to the different parts of the steam system. The proper selection, installation and use of safety valves require a complete understanding of the ASME code and any additional requirements adopted by insurance companies or the local jurisdictional authority.

Documenting safety valves

Maintaining a well-documented database that contains up-to-date records of all safety valves in the steam system is necessary to ensure reliable, safe plant operation. The database should include all relevant information about all safety devices. The plant can rely on this database as it conducts yearly inspections of the Section I and Section VIII BPVC safety valves. The safety valve database should always be updated with the yearly information from inspections and changes based on plant standards and insurance company recommendations, as well as federal, state or local government requirements.

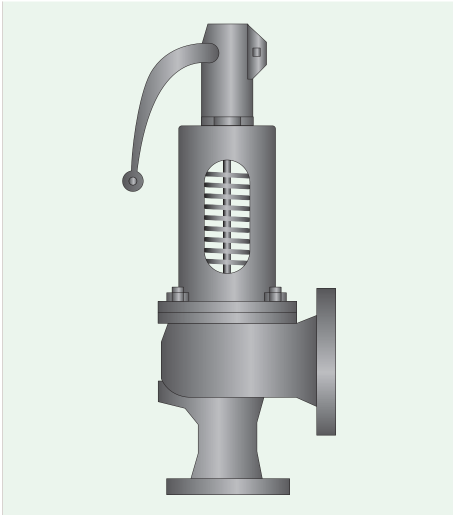

FIGURE 1. A safety valve used in a steam system should meet the rigorous requirements of the ASME Boiler and Pressure Vessel codes

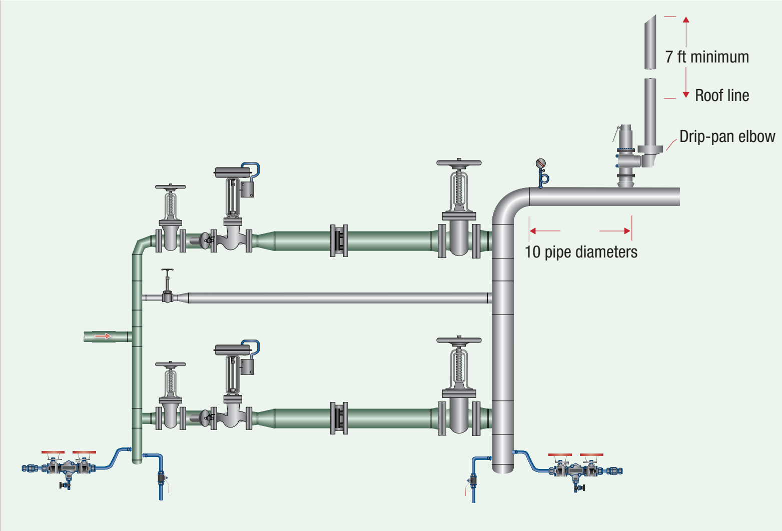

FIGURE 2. A safety valve in a steam line protects against potentially dangerous situations, including excessive steam pressure and high temperatures

Sizing guidelines

When sizing safety valves, plants should follow a number of guidelines to avoid failures and to comply with applicable codes.

First, the setpoint for the safety valve should be set so that there is at least 10% between the operating system pressure and the safety valve set pressure. This will prevent the safety valve from operating in the simmer mode, which the code does allow.

Second, the plant should choose a valve capacity based on the control valve's maximum flow. To do so, engineers should calculate the inlet steam pressure (PI) at the maximum steam pressure, which is the safety valve setting of the steam supply source. The engineer should not calculate using the steam system's nominal operating pressure.

In many cases, it is not possible to install a single safety valve because of high steam capacity or physical limitations. An acceptable alternative is to employ multiple safety valves on the same steam system. The safety valves can have different setpoints so long as the setpoints are below the steam system's maximum design pressure. The total steam capacities must be equal to or greater than the maximum steam flow to the system to ensure that they never exceed the maximum steam pressure.

Keep in mind that the total capacity might change depending on the location of the safety valve. When considering a safety valve downstream of a steam-pressure-control valve, the total capacity of the safety valve at the setpoint must exceed the steam control valve's maximum flow capacity (the largest orifice available from that manufacturer) if the steam valve were to fail in the fully open position.

When a safety valve is installed downstream of a control valve or a regulating valve, and a bypass valve is installed, the bypass valve must always have a smaller diameter than the control valve to ensure it has a lower flow coefficient (Cv) than the control valve. If the bypass is the same size as the control valve, then the safety valve has to be sized for the valve (control valve or bypass) with the higher Cv.

Finally, the plant should adjust the set pressure of the safety valve to be equal to or below the maximum allowable working pressure (MAWP) of the component with the lowest MAWP in the steam system. This includes, but is not limited to, steam boilers, pressure vessels, equipment and piping systems. In other words, if two components on the same system are rated at different pressures, the safety device protecting the steam system for both devices must be set at the lower of the two MAWPs.

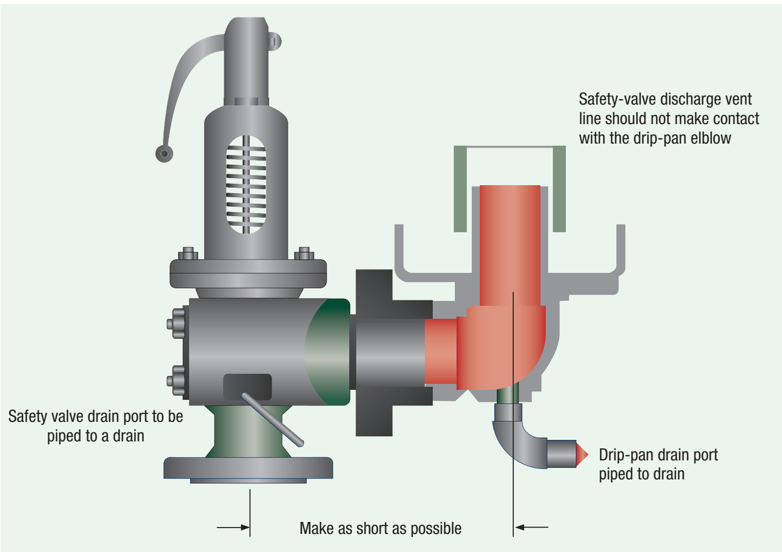

FIGURE 3. There are many aspects to consider when installing a safety valve into a typical steam-system application

Installation guidelines

Figures 3 through 5 show three different types of safety valve installations: Figure 3 shows a typical installation; Figure 4 depicts a safety valve installed after a pressure-reducing valve; and Figure 5 illustrates a safety valve installed on a heat-transfer process. No matter which purpose the safety valve

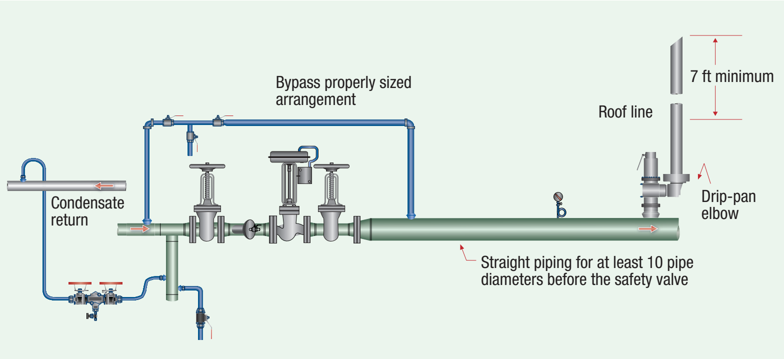

FIGURE 4. Safety valves can be installed downstream of a pressure-reducing valve, as shown in this illustration

serves, the foundation of a successful installation is proper preparation of the steam system. Engineers must ensure the steam system is clean and free of any dirt or sediment. They can prepare the steam piping before installing it or, after installation, by conducting controlled steam blowthroughs.

Plants must keep a number of parameters in mind when choosing a location for the installation. Safety valves should be connected to the steam line independent of any other type of connection. Also, the safety valve should be located as close as possible to the steam line or vessel. Additionally, they must be installed at least 10 pipe diameters downstream of any valve, elbow or other component that could disrupt the steam flow. Finally, safety valves must be mounted vertically. The valve's spindle must be in an upright position and no more than 1 deg away from vertical.

In addition, engineers should review the context of the valve to make sure it does not interfere with safety valve operation. First, check the steam line or pressure vessel. It should be free of any vibration or waterhammer that could change the set pressure of the safety valve. Second, review the inlet steam piping. The inlet steam piping to the safety valve must be equal to or larger than the safety valve inlet connection. For example, if the safety valve has a 3-in. inlet connection, the piping from the vessel or header should be 3 in. or larger. Third, look for any intervening shutoff valves between the safety valve inlet and the steam component. Shutoff valves could isolate the safety valve from the system or could restrict the steam flow to the safety valve. Finally, inspect for plugged or capped drains or vent openings on the body of the safety valve. The purpose of the drain or vent openings is to allow any liquid that might accumulate above the discharge valve to evacuate properly.

Safety valve flanges should be installed according to the appropriate bolt torque specifications, procedures and torque patterns.

When using more than one safety valve, the discharge vent piping must be sized to accommodate the full flow of all safety valves in a fully open position simultaneously when there is no backpressure on the safety valve outlets. For multiple safety valve installations using a single connection, the internal cross-sectional area of the inlet should be equal to the combined inlet areas of all the safety valves.

All safety valves should use a purchased or custom-made drip-pan elbow on the safety valve outlet. Drip-pan elbows improve the performance of safety valves in two ways: they isolate the safety valve from the weight of the safety-valve vent piping; and they change the steam flow at the outlet of the safety valve from horizontal to vertical.

When installing a drip-pan elbow, engineers should remember that the steam will not escape from the drip-pan elbow configuration if the safety-valve discharge vent line is properly sized. In addition, the safety-valve discharge vent pipe should not touch the drip-pan elbow. The discharge vent piping should be supported independently from the safety valve and drip pan elbow assembly to prevent undue stresses on the safety valve. Furthermore, the drains on the drip-pan elbows are designed to collect any condensed liquid and rain, and to allow flow to move safely away from the safety valve, so the drip-pan elbows should not be plugged.

Plants should also mind one additional caveat when it comes to valve installation: be aware of the tempta-

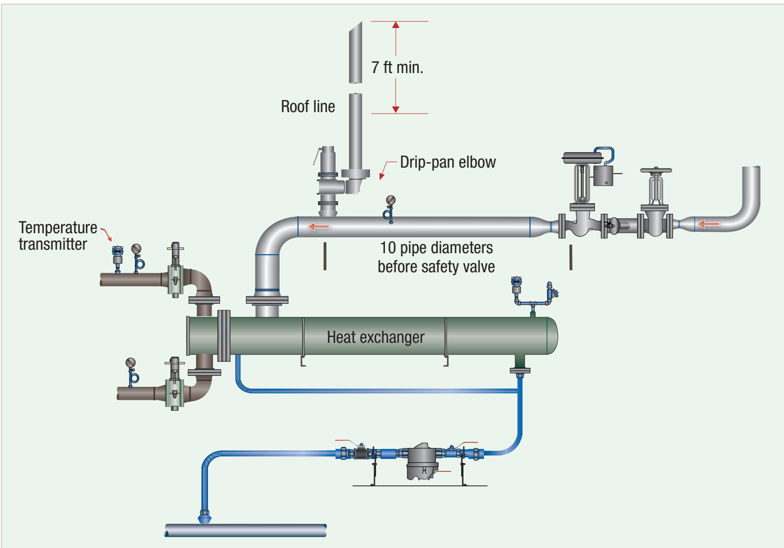

FIGURE 5. Several special considerations should be understood when installing safety valves into heat-transfer applications

FIGURE 6. In this photo, the discharge vent line is attached directly to the safety valve, which is an incorrect configuration that can result in excess stress being placed on the valve body

tion to tamper with safety valve settings. Safety valves are set, sealed and certified by the manufacturer or an authorized and certified assembler to prevent tampering by unauthorized personnel. If the wire seal on the safety valve is not intact, the valve is no longer in compliance with the code, and it should be replaced as soon as possible.

Discharge vent piping

Plants must follow several principles when installing safety-valve discharge vent piping. First, the diameter of the discharge vent pipe must be equal to or greater than the safety valve outlet. Second, the discharge vent line should be sized to avoid creating any backpressure on the safety valve during the discharge mode. Figure 6 depicts an incorrect installation. The discharge vent line is firmly attached to the safety valve outlet, which will put stress on the safety valve. Third, the plant should minimize the length of the discharge vent pipe. A rule of thumb is that if the discharge vent pipe exceeds 30 ft and has more than one elbow, then the discharge vent piping must be increased in size to prevent backpressure on the safety valve.

Finally, the discharge outlet of the vent pipe should be piped to the closest location where free discharge of the safety device will not pose any safety hazard to personnel. The typical safety-valve discharge point is above the roofline or above the plant's operating unit. The safety-valve discharge vent should be no less than 7 ft above the roofline or the operating unit, as Figure 7 shows. The top of the discharge vent line should be cut at a 45-deg angle to dissipate the steam discharge thrust, to prevent capping of the pipe and to visually signify to plant personnel that it is a safety valve vent line. Again, Figure 6 is an incorrect installation since the discharge vent line is firmly attached to the safety valve outlet, which will put stress on the safety valve. Never attach the safety valve discharge vent piping directly to the safety valve, because this will place undue stress and weight on the safety valve body and change the set pressure of the safety valve. A very short section of vent pipe must be used to connect the safety valve drip pan elbow to the safety valve if the drip pan elbow is not directly connected to the safety valve.

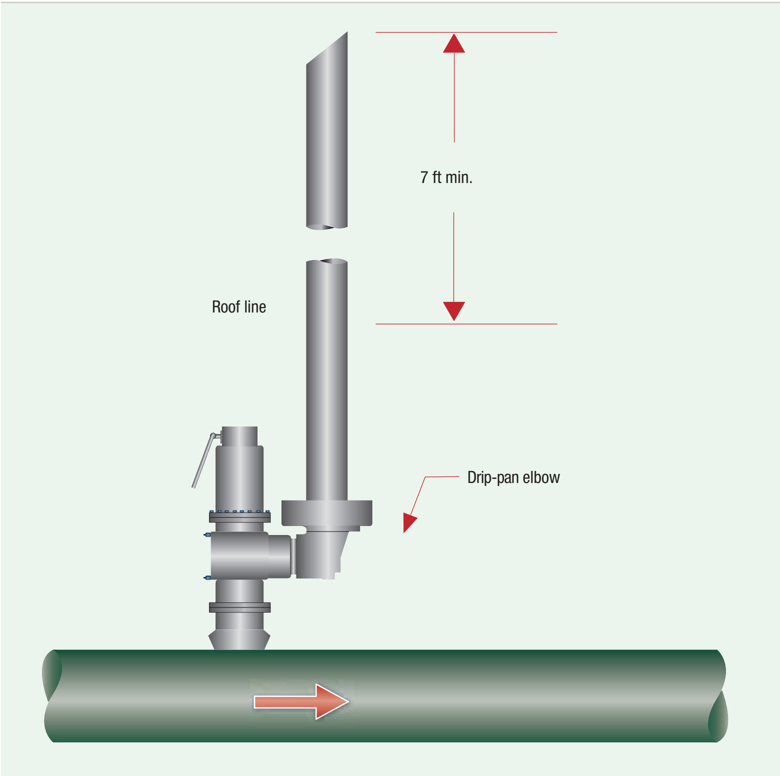

FIGURE 7. The safety valve discharge vent line should be at least 7 ft above the operating unit

Best practice roadmap

There are three primary steps to a successful safety valve operation. First, establish plant standards for safety valve installation and selection. Second, add all safety valves to a database. Finally, review all safety valves periodically, depending on plant standards, insurance company recommendations, and federal, state, or local government requirements. ■

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Setting Specifications in the Modern World

Utilizing 'Tolerance Intervals' can help to set more realistic specification ranges, especially when only small amounts of data are available

Noel Sutton
Amway

Specifications provide a framework by which one can gage whether products have been manufactured successfully. They identify a product's key characteristics and, for each attribute, quantify how much deviation from a target value is allowed. Normally, specification ranges are derived from either the "voice of the customer" (that is, customer requirements) or the "voice of the process" (that is, process capabilities).

For example, when formulating a material that will be sold in tubes, what rheology or flow properties should the product have? Customers ideally want the substance inside the tubes to be stiff enough (with a high enough yield point) so that it won't flow unintentionally, but thin enough that when a reasonable amount of force is applied, the product dispenses. To control this, a viscosity specification would be created to guide manufacturing.

In both cases, whether specifications are dictated by customer or process requirements, development engineers must carry out enough experimentation to uncover how much the product and its properties are affected by innate manufacturing variability. In addition, when specifications are driven by customer needs, one must substantiate that the manufacturing process is capable of unfailingly supplying product that meets those obligations; if the process cannot meet them, then it should be modified until it can.

After collecting pre-production data, how should that information be employed to predict future product variability? The chemical process industries (CPI) currently have no widely accepted, standard way of establishing process capability-based specification limits. Some companies take minimum and maximum values observed during product development and scale-up and then utilize them as specification boundaries. Others rely on statistical concepts, such as the widely known Six Sigma method, to establish acceptance criteria.

When pre-production measurements or test results originate from normally distributed populations — a very common situation — the equations below stipulate the Six Sigma outer limits. They depend on the data's mean, μ, and standard deviation, σ:

Lower release limit (*LRL*) = $\mu - 3\sigma$
Upper release limit (*URL*) = $\mu + 3\sigma$

(*Note*: Six Sigma represents the span of –3 to 3 standard deviations. For large amounts of data, that span covers 99.73% of all measurements if the data are normally distributed.)

What many don't realize is that both specification-setting methods mentioned above are only appropriate when appraising large data sets (containing at least 30, but maybe 50 or more data points). They are invalid when just a few data points have been acquired. However, many companies these days have a conflicting mandate — to shorten product-development schedules so products can be delivered faster to the marketplace. This frequently translates into less time available for experimentation in the laboratory or in pilot plants (and thus, less data generated during preproduction).

When creating specification ranges from a limited number of data points, boundaries generally end up being too close together because small "sample" quantities seldom exhibit the degree of variation found in larger data sets. With undersized or inadequate specification ranges, some future output will be flagged as being out of specification (OOS), when in reality, nothing is wrong with it; the OOS test result or measurement emerged from normal process variation — not some aberration of the manufacturing process.

TABLE 1. VISCOSITY DATA & STATISTICS, CENTIPOISE (CPS)

Batch 1	15,397
Batch 2	14,697
Batch 3	16,796
Minimum	14,697
Maximum	16,796
Mean	15,630
Standard deviation	1,069
Count	3

The Tolerance Intervals method

To balance a company's competing objectives (to be "first to market" versus ensuring outstanding product quality), more businesses should adopt Tolerance Intervals (TIs) as a specification-setting technique. This method compensates for pared-down data sets, and produces wider, more realistic specification ranges while requiring just a fraction of the customary amount of pre-production data. TIs are defined by:

- The number of data points obtained
- The minimum proportion of a population that must be covered by the TI (50, 75, 90, 95 or 99% are typical values picked)
- The confidence level chosen (90, 95 or 99% are common values), indicating the likelihood that the range or interval will cover the proportion of a population selected

TI endpoint equations [*1*] are expressed similarly to the Six Sigma method, with k_2, the tolerance factor for normal, two-sided population distributions, replacing the three values in the earlier definition of *LRL* and *URL*:

LRL = $\mu - k_2\sigma$
URL = $\mu + k_2\sigma$

TABLE 2. COMPARISON OF RELEASE LIMITS DERIVED BY VARIOUS SPECIFICATION SETTING METHODS			
	Min & Max	Six Sigma	Tolerance Interval
Lower release limit (LRL)	14,697	12,424	5,827
Upper release limit (URL)	16,796	18,836	25,433

TABLE 3. VISCOSITY STATISTICS	
Minimum	10,800
Maximum	19,600
Mean	15,609
Standard Deviation	1,995
Count	27

The equation shown below furnishes an approximate value for k_2, where:
N = the number of data points
z = the critical value of a standard normal probability
ρ = the minimum proportion of a population, %
γ = a confidence level, %
χ^2 = a Chi-Square distribution
$x^2_{1-\gamma,N-1}$= Lower tail critical value of Chi-Square distribution
$z_{((1-\rho)/2)}$=Critical value of the standard normal distribution for a cumulative probability of $((1 - \rho)/2)$

A practical example

Recently the author's company developed a new product whose viscosities are very similar to those of another product that has been produced for a while. Three pilot plant batches were made, with the viscosity data and resulting statistics shown in Table 1.

What proportion of a population and confidence level should be chosen when creating the TI specification ranges for this new product? Through some evaluation, the author found that selecting a 99% proportion of a population and a 90% confidence level usually works well, creating specification ranges that are neither too wide nor too narrow.

$$k_2 \sim \sqrt{\frac{(N-1)*(\frac{N+1}{N})*Z^2_{(1-\rho/2)}}{x^2_{1-\gamma,N-1}}}$$

Where:
N = Number of data points = 3
ρ = Proportion of population to be covered = 99%
$z_{((1-\rho)/2))}$ = The critical value of a standard normal probability $= z_{((1-0.99)/2)} = z_{0.005} = -2.58$
$z^2_{((1-\rho)/2))} = (-2.58)^2 = 6.65$

γ = Confidence Level = 90%
$\chi^2_{1-\gamma,N-1}$ = Lower tail critical value of Chi-Square distribution $= \chi^2_{0.1,2}$=0.211
$k_2 = [2*(4/3)*.6.65/0.211]^{0.5} = 9.17$

Thus:

$LRL = \mu - k_2\sigma = 15{,}630 - (9.17*1{,}069) = 5{,}827$

$URL = \mu + k_2\sigma = 15{,}630 + (9.17*1{,}069) = 25{,}433$

Table 2 summarizes the specification ranges created by the three specification methodologies (Minimum/Maximum, Six Sigma and TIs) discussed here. Clearly, the Tolerance Interval release limits are significantly wider than those generated by the other two approaches.

As mentioned previously, the new product's viscosities are very

TABLE 4. PREDICTED OOS FREQUENCY FOR A SINGLE PRODUCT CHARACTERISTIC			
	Min & Max	Six Sigma	Tolerance Interval
Out of specification (OOS) Results	59.7%	10.7%	0.0%

TABLE 5. VISCOSITY DATA & STATISTICS	
Batch 1	394,000
Batch 2	341,000
Batch 3	418,000
Mean	384,333
Standard Deviation	39,400
Count	3

TABLE 6. PROPOSED VISCOSITY RANGES		
	Tolerance interval	Alternative range
Lower release limit (LRL)	23,306	200,000
Upper release limit (URL)	745,361	500,000

similar to those of another product that's been manufactured for a while. Table 3 contains statistics for the established product. Comparing the proposed specification ranges in Table 2 with information acquired from the older product is informative. Assuming both products have identical viscosity-population distributions allows one to estimate OOS frequencies for the three specification ranges (shown in Table 4). This demonstrates how unsuitable the first two methods can be at creating specification ranges for situations involving small data sets.

It should be noted that the OOS percentages listed in Table 4 are for a single quality parameter. If an invalid methodology is used to create the specification limits of more than one quality parameter, the likelihood of making OOS product increases correspondingly. This is illustrated by the two-factor probability equation shown below:

$$P(A \text{ or } B) = P(A) + P(B) - P(A \text{ and } B)$$

If the odds of having OOS product by parameter A are 10%, or by parameter B are 10%, then the odds of having OOS product from either A or B are calculated using the following equation:

$$P(A \text{ or } B) = P(A) + P(B) - P(A \text{ and } B) = (1/10)+(1/10) - [(1/10)*(1/10)] = 19\%$$

Considering the negative consequences typically associated with manufacturing OOS products, they should be avoided, especially when they arise from routine variation, not from a process deviation that could adversely impact a product's quality.

Admittedly, small data sets sometimes contain considerable variability. Applying the Tolerance Interval method to such data can lead to very wide specification limits that are neither feasible nor desirable. For instance, the lower viscosity-release limit could end up as a negative number, which is physically impossible. In all instances, before calculating a TI, the following should be done:

Check for and exclude outliers/anomalies from the data set. Several statistical methods are available for detecting outliers.

If the calculated TI is still wider than expected or desired, proceed with one of the following options:

Option 1. Propose a narrower, more pragmatic specification range and identify what confidence level corresponds with it. The confidence level associated with a tighter, but more reasonable, specification range can be computed. If the confidence level turns out to be sufficiently high, the adjusted specification range should be adopted. An example of how to do this is discussed below.

Option 2. Generate some supplementary preproduction data. Producing just a few additional test results (not the 30–50 data points required by other specification setting techniques) ordinarily leads to enough convergence between observations so that the Tolerance Interval will shrink considerably. The k_2 value is driven down through increased knowledge about the new product, and the standard deviation generally decreases as well. This is demonstrated in an example below.

TABLE 7. EFFECT OF UTILIZING ADDITIONAL DATA POINTS ON TOLERANCE INTERVALS			
	Drug active #1	**Drug active #2**	**Drug active #3**
Desired release limits	2.7 – 3.3	6.75 – 8.25	0.45 – 0.55
	LRL – URL	*LRL – URL*	*LRL – URL*
3 Sets of test results	2.56 – 3.27	6.05 – 8.99	0.43 – 0.58
6 Sets of test results	2.72 – 3.17	6.79 – 8.16	0.47 – 0.53

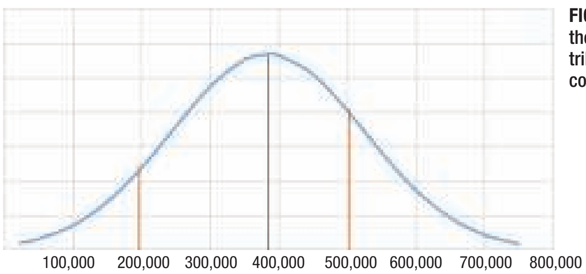

FIGURE 1. Shown here is the predicted population distribution for the calculating confidence level example

Calculating confidence level

Discussed next are recommendations for calculating the confidence level of a designated specificaiton range. Table 5 shows viscosity data associated with a very thick product. Since these data were not consistent, the proposed viscosity range using Tolerance Intervals, as shown in the middle column of Table 6, was quite wide. The *LRL* (at a 90% confidence level) was unacceptably low at only 23,306 cps. As a result, an alternative viscosity range of 200,000–500,000 cps was proposed and evaluated. What confidence level coincides with that range when 99% of future production viscosities must fall within that range?

Referring to Figure 1, since the average viscosity of 384,333 is not the midpoint of the proposed range of 200,000 – 500,000, both sides of the population distribution will be examined separately. For the lower tail of the distribution:

$$LRL = \mu - (k_L * \sigma)$$

$$k_L = (\mu - LRL)/\sigma = (388{,}333 - 200{,}000)/39{,}400 = 4.68$$

$$x^2_{(1-\gamma, N-1)} = \frac{(N-1)*[(N+1)/N]*z^2_{(1-\rho)/2}}{(k_L)^2}$$

$$= [2*(4/3)]*(-2.5758)^2/(4.68)^2 = 0.0803$$

To determine 1–γ one should specify the degrees of freedom (*N*–1) and calculate the Chi-square cumulative distribution function (Some spreadsheet programs or online calculators can do this computation). The result is 0.332.

The confidence level for the lower portion of the specification range is:

$\gamma = 1 - 0.332 = 66.8\%$

This means there is a 66.8% confidence level that future test results will be > 200,000 cps.

Performing similar calculations on the upper portion of the prospective specification range reveals that there is only a 35.8% confidence level that prospective viscosities will be < 500,000 cps.

In situations like this, where the confidence level is not very high, a risk assessment should be carried out. Is there a high likelihood that OOS results will occur down the road? If the risk of generating OOS results is unacceptably high, select one of the options below:

1. *Widen the proposed release limits and recalculate the confidence level for the new range.* This can be repeated in an iterative fashion until an acceptable confidence level is reached, or
2. *Produce additional preproduction data as mentioned in Option 2 above.* Low confidence levels indicate high levels of statistical uncertainty. Producing just a few additional test results (not the 30–50 data points required by other specification setting techniques) will help to decrease the TI. The discussion that follows next illustrates this option.

Reducing Tolerance Intervals

Providing supplementary information can help to reduce TIs. With over-the-counter drugs, the *LRL* and *URL* for active ingredients are typically set at or within 10% of the target level. Table 7 provides an example of a situation that involved augmenting the initial test data. As shown, the row with the sought-after release limits is highlighted. Below that, Tolerance Intervals were calculated using test results from only three pilot batches. All TIs were wider than the targeted release limits — not desired.

The effect of supplementing the original data with test results from three additional pilot batches is shown on the bottom row of Table 7. Each TI contracted considerably, with all TIs now falling inside the prescribed boundaries. This demonstrates how supplying just a few extra data points can have a pronounced impact on a TI because statistical uncertainty is reduced. ■

Edited by Suzanne Shelley

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Training Today's Workforce

Integrated console, virtual-reality simulation offers learning for maximum, measurable training efficiency

Graham Provost
Schneider Electric Industry Business

Modern techniques are being used for realistic plant training for control room operators, field operators, and operations and maintenance personnel. Simulator training has been shown to result in better retention by participants than most other learning methods. This article describes these training platforms, when they should be used, and how to set up a performance-based competency grid.

Simulation training and blended learning can be tied to an organization's key performance indicators (KPIs) through a Personnel Effectiveness Model that utilizes simulation to maximize training value for time spent.

To understand how to employ a Personnel Effectiveness Model, consider first that time spent in structured, measurable simulation training is significantly more valuable than time spent by any other learning method [*1*]. Simulator training achieves 78% retention, while the average of all other methods is 11.6% when blended equally (Figure 1). This means that simulator training is nearly seven times more effective than any other learning method, not including on-the-job training (OJT). In many cases, even OJT is unstructured and not measurable. While this experiential learning is valuable, it can also be accomplished using simulation.

Therefore, it is reasonable to say that one, 8-hour day of simulator training is effectively worth 7 days, or 56 hours of training by any other method. The Personnel Effectiveness Model considers that technical competency should be one of an organization's KPIs. This is true for most large industrial organizations, however historically, most have a difficult time measuring the effectiveness of time spent in training and overall competency of their employees. In addition to the classic reasons to use simulation, such as "reduce trips" and "speed time to commissioning," employing structured simulation training and other modern methods, such as tutorial video and virtual reality simulation, maximizes the value of the time spent in training.

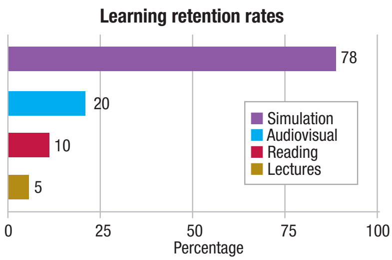

FIGURE 1. Simulation offers a 78% learning retention rate, which is much higher than other training options (Source: Ref. 1)

Integrated platform for O&M

A complete, integrated simulation and training platform can be used to train control room, and field operations and maintenance (O&M) personnel through the development of targeted models and trainee activities. These solutions typically consist of portions of control-panel-based simulation, which are traditional operator training simulators (OTS), integrated with small virtual-reality (VR) training environments. Learning is targeted at high-consequence, difficult and important items. Both operations and maintenance training are considered, and scenarios are built to accommodate items such as production, abnormal operations (O&M team training), maintenance and repair procedures.

By developing and deploying a training platform such as this, organizations are able to maximize the effectiveness of the time personnel spend in training, and raise their level of retention and therefore competency. VR platforms also enable inclusion of items such as orientation, and environmental, health and safety electronic-learning as part of the dedicated training environment.

When should simulation be used?

All O&M training items can and should generally be accomplished using simulation of various types, with the exception of true tactile feedback and maintenance-related psychomotor skills. The benefit of a simulation platform is that it is always available and can be set up for trainee self-study. This alleviates some of the training responsibility that often falls on senior personnel, whose time is already stretched thin.

In addition, simulation training can also be deployed over the "cloud," making global deployment and management a possibility. A competency grid should be constructed assuming that simulation will accommodate the training. This is antithetical to the traditional practice that we must first identify what can be accomplished with simulation. This mindset is obsolete because modern simulation can replicate nearly any environment and condition.

The modern competency-grid model should be built such that, at the end of the analysis, we identify exception items that should be physically experienced based upon those that affect the KPI-related training scenarios to be built. This maintains the focus on performance and training as related to the solution that is being designed.

Competency grid model

Constructing a performance-based competency grid for a facility or workgroup is a scientific process

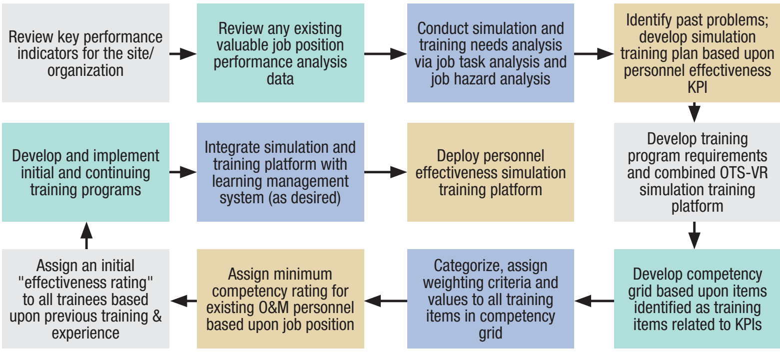

FIGURE 2. This graphical depiction of a personnel effectiveness competency model shows the steps involved

that serves as the foundation for any training program. It is what tells the management team what training their people need, given the facility's current KPIs. It can be accomplished by a dedicated workgroup experienced in instructional systems design at industrial facilities. The steps involved in the work include the following (Figure 2):

1. Review key performance indicators for the site or organization
2. Review existing, valuable, job-position performance analysis data
3. Conduct a simulation and training needs analysis
   a. Job task analysis — Conduct a performance review of control room, field operator and maintenance job positions to determine the difficulty, importance and frequency of normal and abnormal operations expected
   b. Identify items that directly relate to KPIs, such as those that directly affect production, personnel safety and environmental compliance
   c. Job hazard analysis (JHA) — O&M tasks with high consequence JHAs should be considered for simulation training as well as those that affect KPIs
   d. Past problems — Identify any past problems or incidents that should be included in training
   e. Develop a simulation training plan based upon personnel effectiveness KPIs
4. Develop training program requirements and combined OTS-VR simulation training platform.
5. Develop a competency grid based upon items identified as training items related to KPIs
6. Categorize and assign weighting criteria and values to all training items in the competency grid
7. Assign minimum competency ratings for existing O&M personnel based upon job position
8. Assign an initial "effectiveness rating" to all trainees based upon previous training and experience
9. Develop and implement initial and continuing training programs
10. Integrate simulation and training platform with a learning management system (as desired)
11. Deploy personnel effectiveness simulation and training platform

Personnel effectiveness rating

Table 1 represents a simplified example of a completed competency grid for personnel consisting of 48 discrete training items. Let's consider that it takes 200 hours to complete all training items in the grid and that there are 100 total persons at the site. Assuming an average hourly rate (O&M, supervision) of $50 per hour, it costs $1,000,000 to implement all of the items in the grid per 100 persons. If personnel effectiveness is considered as a KPI for an organization, then we should also consider this training seat time to be an asset expenditure on personnel competency and growth.

Using integrated simulation and training applications raises the return on competency investment by enabling 78% retention, as compared to an average of 11.6% for all other methods. In the example below, shown for a combined O&M worker, we can also directly correlate her or his 84.5% personnel effectiveness rating to training and retention cost. This also allows organizations to tie effectiveness ratings to pay scale, bonus or promotion as a measurable element for the worker.

If the training was given in traditional non-simulation ways, such as required reading, lecture and so on, that have a cumulative retention rating of 11.6%, the return on investment in training is only $116,000. Using simulation for the same activities improves the training experience for all users and raises the ROI in training time to $780,000. This example equates to $664,000 of wasted training time investment, or approximately 13,280 hours of wasted time spent in largely ineffective and often unenjoyable training by employees just to complete their required qualifications.

The importance of flexibility

Of course all of this takes time and money, and we recognize there is a finite amount of this every year. That's why getting the most value for time and money spent is so important. One of the benefits of employing a virtual reality or "immersive training" environment (Figure 3) is that it can be expanded and updated year after year even if the control system is changed.

FIGURE 3. Virtual and augmented reality can be combined in immersive operations training

TABLE 1. COMPLETED COMPETENCY GRID EXAMPLE

Trainee Name	O&M Personnel Effectiveness Rating 84.5%						
Competency Area	Competency Group	Simulation & Training Competency Item (each column represents a different item)				Area Effectiveness Rating	Maximum Score
Integrated O&M Scenario Team Training (item value)	High-value team training	10	10	10	10	36	40
(trainee score)		90%	85%	90%	92%		
Operations Personnel	Integrated panel op / field training	9	9	9	9	28.8	36
		75%	76%	75%	94%		
	Panel operator training scenarios	8	8	8	8	22.16	32
		42%	71%	78%	86%		
	Field operator training scenarios	6	6	6	6	19.68	24
		75%	78%	94%	81%		
	Operator fundamentals	4	4	4	4	15.52	16
		100%	100%	100%	88%		
Maintenance Personnel	Maintenance procedures	7	7	7	7	21.49	28
		87%	100%	62%	58%		
	Maintenance fundamentals	4	4	4	4	14.92	16
		100%	81%	92%	100%		
All O&M Personnel	Past problems and incidents (industry-wide)	6	6	6	6	22.92	24
		100%	96%	100%	86%		
	System-based fundamentals	5	5	5	5	16.8	20
		89%	92%	72%	83%		
	Core training (fundamentals)	3	3	3	3	10.38	12
		82%	79%	95%	90%		
	Site EH&S	1	1	1	1	3.75	4
		100%	100%	85%	90%		
	Site orientation	1	1	1	1	4	4
		100%	100%	100%	100%		
Total Effectiveness Score	**84.5% in this example (based on a score of 216.42 out of 256)**					**216.42**	**256**

A good VR environment will allow connection to more than one control system so that the client is not "locked in" to one VR vendor. It is also practical to enter into multi-year service agreements where the platform is designed and developed as part of a capital expense (capex) project in year one with subsequent development in following years under the same expenditure. In subsequent years, operational expenses (opex) can also be used to add additional training items and scenarios to the VR environment to raise the effectiveness of training provided, thereby raising the effectiveness of personnel. This is also especially important as overall training needs change over the years.

Personnel effectiveness & KPIs

Using a model for personnel competency development that incorporates the most efficient and effective training methods available is an important factor for responsible managers. Given the technology options that exist today, it hardly makes sense to just rely on approaches that were developed nearly two decades ago — including PowerPoint presentations or overhead projectors. Research findings have validated the inefficiencies of these methods. We know these approaches are ineffective, and therefore a poor choice both for the experience of the trainee as well as for the longterm investment that is made in training time and competency development at any facility.

Using a personnel effectiveness training model and deploying simulation and training in immersive, experiential environments can give an organization a sustainable model for competency development that quantifies the value of advanced training applications, time and activities. In addition, it is true to say that a more competent, effective O&M workforce will undoubtedly raise the quality and value of production and any other targeted KPI if an effective simulation training model is employed. This model can lend increased credibility to training practices at industrial facilities by tying the activities directly to KPIs and high consequence items determined through a rigorous scientific method with room for evolution.

Using an immersive, integrated simulation and training platform to train today's workforce quantifies and maximizes the value of training time and helps to monetize the value of providing better tools for training. The next time someone asks how to quantify the value of training and how it is best delivered, don't be afraid to answer … and don't be afraid to recommend the use of simulation as an economical, powerful and highly efficient option that can deliver far more than you had previously thought possible. ■

Edited by Dorothy Lozowski

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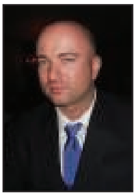

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3	18	33	48	63	78	93	108	123	138	153	168	183	198	213	228	243	258	273	288	303	318	333	348	363	378	393	408	423	438	453	468	483	498	513	528	543	558	573	588
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8	23	38	53	68	83	98	113	128	143	158	173	188	203	218	233	248	263	278	293	308	323	338	353	368	383	398	413	428	443	458	473	488	503	518	533	548	563	578	593
9	24	39	54	69	84	99	114	129	144	159	174	189	204	219	234	249	264	279	294	309	324	339	354	369	384	399	414	429	444	459	474	489	504	519	534	549	564	579	594
10	25	40	55	70	85	100	115	130	145	160	175	190	205	220	235	250	265	280	295	310	325	340	355	370	385	400	415	430	445	460	475	490	505	520	535	550	565	580	595
11	26	41	56	71	86	101	116	131	146	161	176	191	206	221	236	251	266	281	296	311	326	341	356	371	386	401	416	431	446	461	476	491	506	521	536	551	566	581	596
12	27	42	57	72	87	102	117	132	147	162	177	192	207	222	237	252	267	282	297	312	327	342	357	372	387	402	417	432	447	462	477	492	507	522	537	552	567	582	597
13	28	43	58	73	88	103	118	133	148	163	178	193	208	223	238	253	268	283	298	313	328	343	358	373	388	403	418	433	448	463	478	493	508	523	538	553	568	583	598
14	29	44	59	74	89	104	119	134	149	164	179	194	209	224	239	254	269	284	299	314	329	344	359	374	389	404	419	434	449	464	479	494	509	524	539	554	569	584	599
15	30	45	60	75	90	105	120	135	150	165	180	195	210	225	240	255	270	285	300	315	330	345	360	375	390	405	420	435	450	465	480	495	510	525	540	555	570	585	600

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See bottom of opposite page for advertising sales representatives' contact information ←

Classified Index July 2017

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2015 2016 2017

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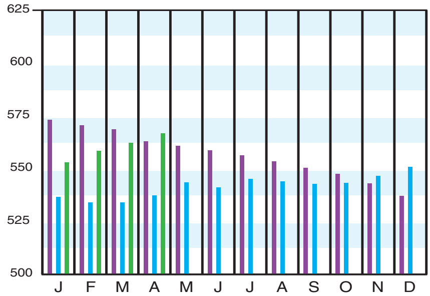
CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957-59 = 100)	Apr. '17 Prelim.	Mar. '17 Final	Apr. '16 Final
CE Index	566.8	561.9	535.3
Equipment	684.2	676.6	638.0
Heat exchangers & tanks	600.9	590.9	545.2
Process machinery	672.2	672.1	644.8
Pipe, valves & fittings	885.0	863.7	800.3
Process instruments	404.4	403.2	383.0
Pumps & compressors	978.6	982.3	969.7
Electrical equipment	515.5	514.3	508.3
Structural supports & misc	735.7	733.3	697.4
Construction labor	324.6	325.8	323.3
Buildings	556.7	555.1	538.4
Engineering & supervision	315.2	314.7	315.7

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

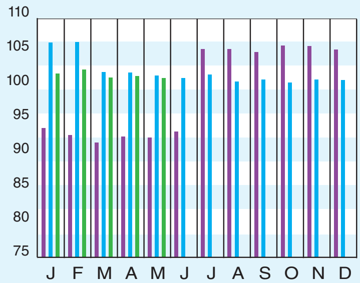
Annual Index:
2009 = 521.9
2010 = 550.8
2011 = 585.7
2012 = 584.6
2013 = 567.3
2014 = 576.1
2015 = 556.8
2016 = 541.7



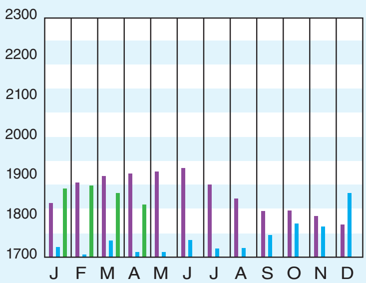
CURRENT BUSINESS INDICATORS

CURRENT BUSINESS INDICATORS	LATEST	PREVIOUS		YEAR AGO
CPI output index (2012 = 100)	May '17 = 101.2	Apr. '17 = 101.1	Mar. '17 = 100.9	May '16 = 100.4
CPI value of output, $ billions	Apr. '17 = 1,831.9	Mar. '17 = 1,830.1	Feb. '17 = 1,842.8	Apr. '16 = 1,690.2
CPI operating rate, %	May '17 = 76.1	Apr. '17 = 76.0	Mar. '17 = 75.8	May '16 = 75.9
Producer prices, industrial chemicals (1982 = 100)	May '17 = 257.3	Apr. '17 = 256.5	Mar. '17 = 251.8	May '16 = 226.9
Industrial Production in Manufacturing (2012=100)*	May '17 = 103.3	Apr. '17 = 103.7	Mar. '17 = 102.6	May '16 = 101.9
Hourly earnings index, chemical & allied products (1992 = 100)	May '17 = 174.6	Apr. '17 = 177.4	Mar. '17 = 172.3	May '16 = 163.7
Productivity index, chemicals & allied products (1992 = 100)	May '17 = 101.2	Apr. '17 = 100.9	Mar. '17 = 102.2	May '16 = 102.0

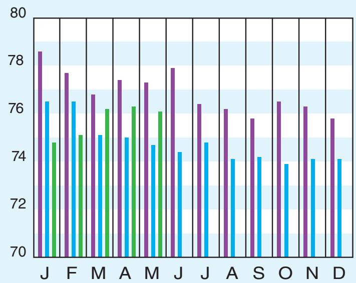
CPI OUTPUT INDEX (2000 = 100)†



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 preliminary value for the April *CE* Plant Cost Index (CEPCI; top; most recent available) rose compared to the previous month's value, making it the seventh straight month of increasing values. The gain in the overall PCI was driven by significant jumps in several categories within the Equipment subindex, such as Pipes, Valves & Fittings and Heat Exchangers & Tanks. The Buildings and Engineering & Supervision subindices increased slightly in April, while the Construction Labor subindex declined by a small margin. The preliminary overall monthly CEPCI value for April 2017 stands at 5.4% higher than the corresponding value from April 2016. Meanwhile, the latest Current Business Indicators (CBI; middle) saw the CPI Output Index for May edge upward slightly.