CHEMICAL ENGINEERING 03 MANAGING STEAM SYSTEMS • PREVENTING COMBUSTIBLE DUST EXPLOSIONS VOL. 122 NO.3 MARCH 2015

CHEMICAL ENGINEERING

March 2015

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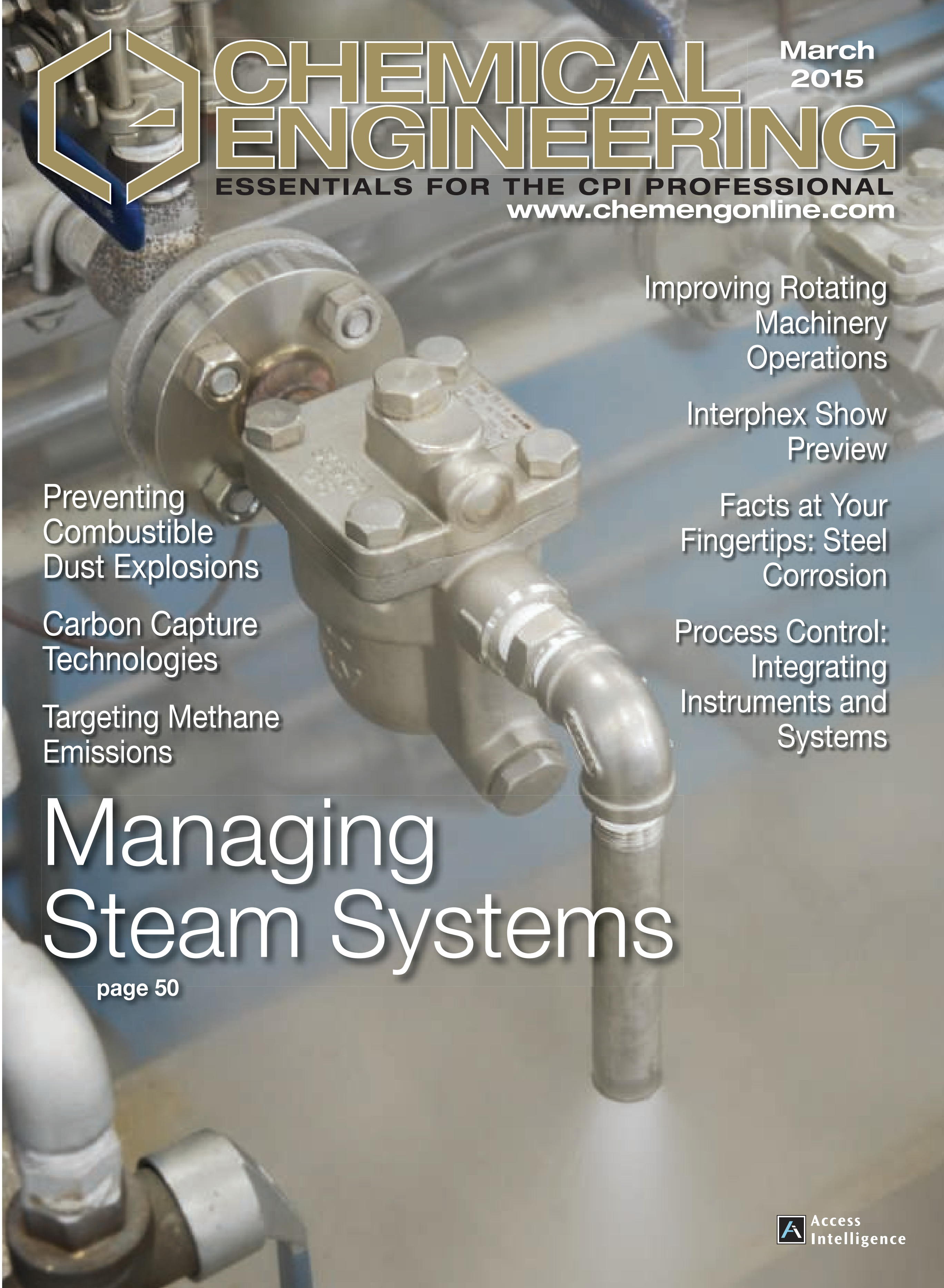

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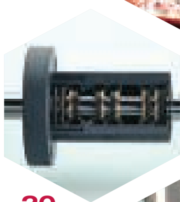

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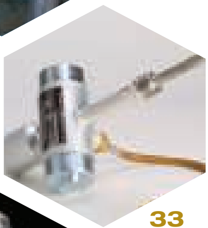

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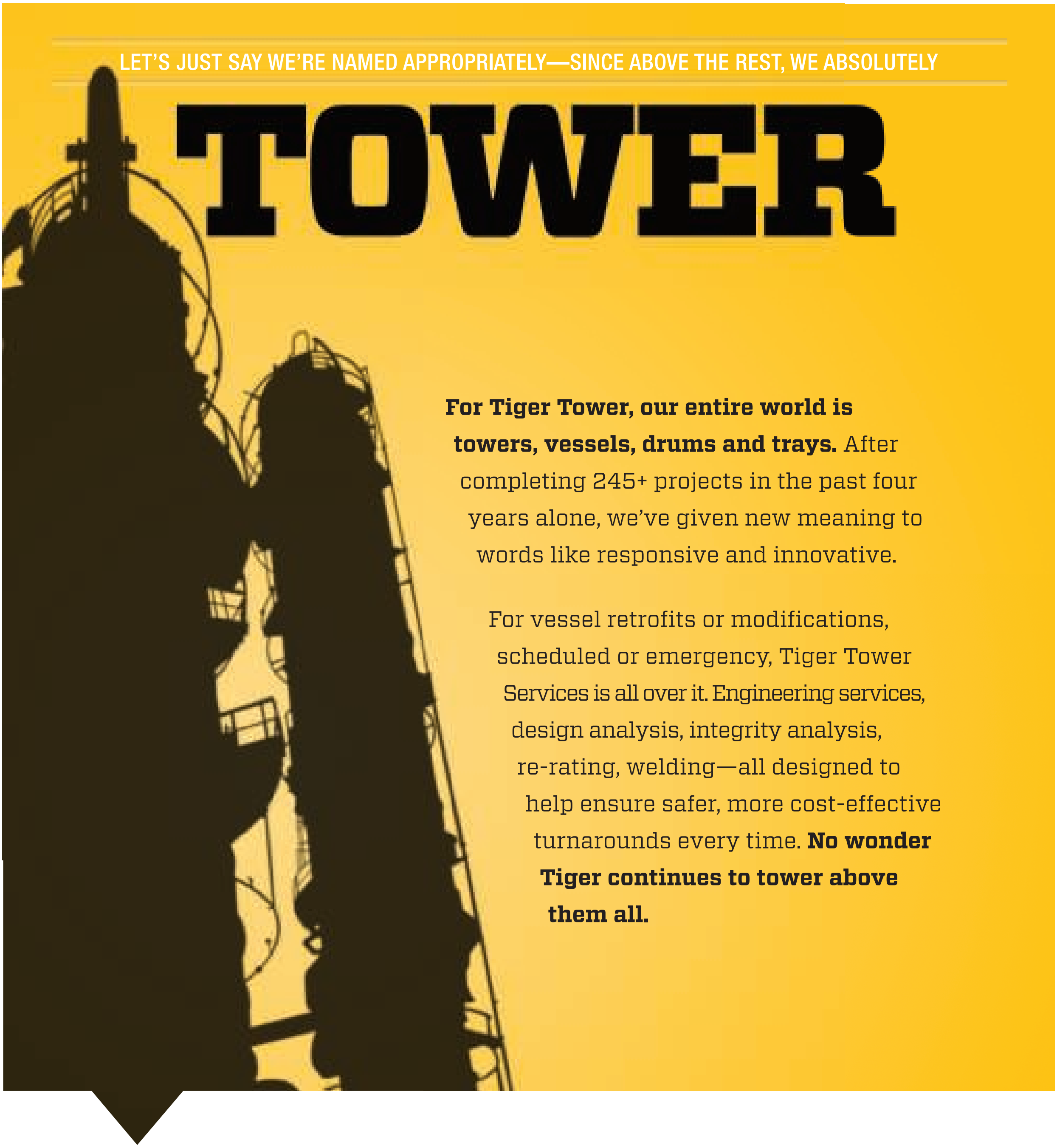

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BPA

Editor's Page

A 'most wanted' safety improvement

In the chemical process industries (CPI), dust can present an issue far more menacing than a housekeeping nuisance. Combustible dust is in fact, much too often listed as a cause of serious, and even fatal accidents.

Incidents

In January of this year, the U.S. Chemical Safety Board (CSB; Washington, D.C., www.csb.gov) issued its report on the U.S. Ink plant flash fire that burned seven workers. This incident, which occurred in October 2012 in East Rutherford, N.J., was found to have resulted from the accumulation of combustible dust inside a dust-collection system that had been put into operation four days prior to the accident. One of the key findings in the report is that while the dust-collection system was designed for dust collection, it was modified to include a housekeeping function, which caused insufficient flowrates. The CSB report notes that the volume of air flow and the air velocity were below industry recommendations.

In 2006, the CSB issued a comprehensive report on combustible dust hazards that was based on investigations of three major industrial explosions that occurred in the U.S. in 2003 alone. The three incidents, in North Carolina, Kentucky and Indiana, cost 14 lives and numerous injuries. In that 2006 study, the CSB identified 281 combustible-dust incidents that occurred in the previous 25 years and claimed 119 lives with over 700 injuries. Since 2006, the CSB documented 50 combustible-dust incidents that resulted in 29 fatalities and 161 injuries. These include the 2008 Imperial Sugar disaster near Savannah, Ga., and three incidents over a six-month period in 2011 at a powdered-metal plant in Gallatin, Tenn.

Standards and regulations

What is striking in the reports about dust explosions is that at least in some cases, known engineering controls may have been preventative. In its 2006 investigation report "Combustible Dust Hazard Study," the CSB recommended that the Occupational Safety and Health Admin. (OSHA; Washington, D.C.; www.osha.gov) issue a standard to prevent combustible-dust fires and explosions based on standards already available from the National Fire Protection Agency (NFPA; Quincy, Mass.; www.nfpa.org). The CSB reiterates this recommendation in numerous subsequent reports including its most recent one issued in January. While standards exist, they are voluntary and not enforced through federal regulations. In 2013, the CSB designated a comprehensive general industry standard for combustible dust as its first "Most Wanted Chemical Safety Improvement."

Resources

In the meantime, a wealth of information about combustible dust is available. The CSB website contains many lessons learned from incident investigations in both report and video format. The NFPA offers a number of relevant standards. OSHA offers various resources, including information on its Combustible Dust National Emphasis Program (NEP). And numerous articles, such as the Feature Report in this issue (Prevent Combustible Dust Explosions With Nitrogen Inerting, p. 64) help to share knowledge and insight into this important issue. ■

Dorothy Lozowski, Editor in Chief


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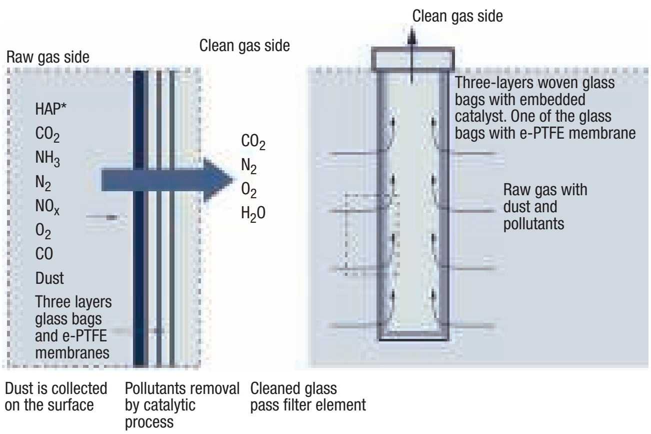
Catalytic filter bags can slash investment costs for offgas treatment

Edited by:
Gerald Ondrey

Last January, Haldor Topsøe A/S (Lyngby; www.topsoe.com) and FLSmidth A/S (Copenhagen, both Denmark; www.flsmidth.com) began a joint, global effort to commercialize a new catalytic filter-bag technology, which the partners have developed over the past four years. Tradenamed EnviroTex, these filter bags are capable of reducing dust, volatile organic compounds (VOCs) and oxides of nitrogen (NOx) in a single, integrated process, says Mikkel Nygaard Larsen, general manager, marketing and sales at Haldor Topsøe. Because EnviroTex treats several pollutants in a single step, the physical footprint of the treatment process is reduced compared to alternative technologies that require separate, standalone systems to handle a specific pollutant, says Nygaard Larsen, and capital expenditures (capex) are significantly reduced — "by as much as 80% for some applications."



*Organic HAP includes formadehyde, benzene, toluene, styrene (m-, p-, o-) xylene, acetaldehyde and napthalene

The patent-pending EnviroTex filter bags consist of three layers of filter fabric, each of which contains a tailored catalyst that has been optimized for removing specific pollutants from offgases (diagram). The three-layer fabric has a porous, woven structure and the catalyst is a mixture of active base and precious metals. As the offgas passes through the filter, dust is filtered on the first layer, and pollutants are catalytically decomposed into harmless compounds (CO_2, N_2, O_2 and H_2O). Even under "the highest" dust load, EnviroTex will remove particulate matter to below 2 parts per million, says Nygaard Larsen. VOC and NOx removal is typically more than 90% of the incoming concentration, he says.

The new filters are said to be suitable for a wide range of industries, including cement, glass and steel production; power generation; waste incineration; and coffee and grain roasting. The new filters will be manufactured at FLSmidth's bag-production facilities in Evans, Ga. The bags will then be "catalyzed" and assembled at Topsøe's production site in Houston. Topsøe's production site will be expanded to include a new production line dedicated to producing EnviroTex. Construction on this facility is slated for the end of 2015.

COMPOSITE COATING

A new composite material that prevents metal corrosion, even under extreme conditions, has been developed by researchers from the INM – Leibniz Institute for New Materials GmbH (Germany; www.inm-gmbh.de). The patented composite consists of layers of particles placed on top of each other in a staggered fashion, creating a self-organized, highly structured barrier, says Carsten Becker-Willinger, head of the Nanomers Program Division. The protective layer is just a few micrometers thick and prevents penetration by gases and electrolytes. It provides protection against corrosion caused by aggressive aqueous solutions, including salt and acids, as well as corrosive gases under pressure.

After thermal curing, the composite adheres to the metal substrate, is abrasion-stable and impact-resistant. It can be applied by spraying or other commonly used wet-chemistry processes, and cures at 150–200°C. It is suitable for steels, metal alloys and metals such as aluminum, magnesium and copper, and can be used to coat

(Continues on p. 8)

This process enables Mg alloy to be cast economically

The New Energy and Industrial Technology Development Organization (NEDO; Kawasaki; www.nedo.go.jp) and Sankyo Tateyama Inc. (Takaoka, both Japan; www.st-grp.co.jp) have developed technology that enables the casting of small-diameter (500–100-mm dia.) magnesium-alloy billets, which are suitable for direct, compact forging. The production costs are said to be half those of existing technology, which involves an expensive and inefficient extrusion and forging process. The breakthrough is expected to enable a wider application of magnesium in automotive, consumer electronics and robotic products as an alternative to aluminum and iron.

The new casting procedure uses an adiabatic, structured template, which suppresses the coagulation of the melted materials within the template and enhances the rapid quenching and coagulation by means of cooling water injected at the bottom of the template. This procedure enables the structural refinement and formation of a dense solid texture, with average crystal-grain size of 50 µm, and a dendrite arm spacing (DAS; a measure of the metal's microstructure) of less than 15 µm. These parameters are about half those generated by existing billet-formation technology, and thus show that the magnesium-alloy billet has a significantly finer and homogeneous coagulation texture.

Sankyo Tateyama has begun shipping samples of the cast billets. The partners have also started to develop multi-face, concurrent continuous casting technology, which will enable mass production.

Note: For more information, circle the 56-digit number on p. 82, or use the website designation.

any shape of plates, pipes, gear wheels, tools or machine parts. The composite does not contain chromium VI or other heavy metals.

SELECTIVE MEMBRANE

New selective hollow-fiber membranes that could enable water purification in a single step have been developed by researchers from the University of Twente's (www.utwente.nl) MESA+ Research Institute, in collaboration with Pentair (Enschede, both the Netherlands; www.pentair.com). The membranes make it possible to purify water in a single process step (eliminating pretreatment required in existing water-treatment plants) while removing micropollutants, such as pharmaceutical residues (medicine residues, hormones and pesticides).

The selective membrane is applied to thin porous straws (5-nm pore sizes). Multiple thin layers of polymer coating (of about 2-nm thick) are applied over the holes by means of a relatively simple chemical process that avoids solvents. Creation of the polymer layers can be controlled very accurately, so the number of layers, the density and the charge of the layers, and so on, can be chosen to suit the desired application.

Modules containing more than 10,000 of the fibers (1-m long) can be numbered up for an industrial water-treatment plant. Pentair is taking over the further product development of the membrane.

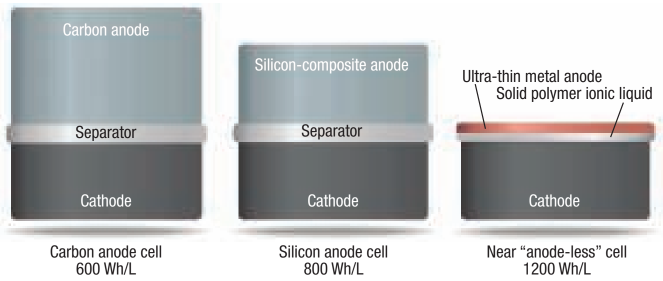
'GREEN' TIRES

At last month's Tire Technology Expo (February 10–12; Cologne, Germany), Solvay S.A.'s Silica business unit unveiled Efficium, which the company says is a breakthrough highly dispersible silica (HDS). Used as a reinforcing filler, Efficium allows for higher productivity and greater flexibility in producing "green" tire compounds for cars and trucks.

(Continues on p. 14)

'Anode-less' lithium battery prototype doubles energy density

A new prototype lithium battery with a very thin metal anode achieves an energy density of 1,200 W-h/L at room temperature — double that of conventional Li-ion batteries using graphite anodes. The prototype battery, developed by Massachusetts Institute of Technology's (MIT; Cambridge, Mass.; www.mit.edu) spin-off SolidEnergy (Waltham, Mass.; www.solidenergysystems.com), uses a standard lithium-cobalt oxide (LCO) cathode with an ultrathin, two-layer, lithium-on-copper anode that allows larger energy density. SolidEnergy has developed a specialized electrolyte that allows the system to work.



"The key know-how is really in the electrolyte," says Qichao Hu, "because conventional electrolytes do not work with this kind of battery system." SolidEnergy's electrolyte has two parts: a liquid around the cathode and a solid polymer composite electrolyte on the anode of the battery. To make it work at room temperature, SolidEnergy developed a proprietary mixture of ionic liquids, a new salt species and other new materials with high conductivity and efficiency.

SolidEnergy partnered with fellow MIT product A123 Venture Technologies (Waltham, Mass.; www.a123systems.com) to fabricate the prototype. Going forward, SolidEnergy will focus on supplying the new electrolytes and anode materials to large manufacturers of Li-ion batteries used in consumer electronics and other applications. The company plans a pilot facility, to be completed in late 2016, that will be able to produce the materials for the equivalent of 30 million cell phone batteries per year, says Hu.

Scaleup for modular H_2 production via PEM electrolysis

Two new proton-exchange-membrane (PEM) electrolysis systems have debuted, targeting applications that require large volumes of hydrogen. Prior to the launch of Proton OnSite's (Wallingford, Conn.; www.protononsite.com) M1 and M2 modular H_2-generation systems, the largest capacity commercially available from PEM modules was just 30 m^3/h H_2, says the company. The M1 and M2 systems can produce 200 m^3/h and 400 m^3/h of H_2, respectively, representing an intensive scaleup effort. Multiple units can be connected to achieve even greater production capabilities for huge-scale projects. In order to reach these higher capacities while ensuring safe operation, the M1 and M2 were designed with a specific emphasis on the differential pressure (DP) between the H_2 and O_2 sides of the membrane. Maintaining a DP of 30 bars across the membrane minimizes gas crossover problems, and also allows the system to produce a very high-quality H_2 stream. Furthermore, this DP approach enables a simplified, low-pressure water-circulation loop that removes any hazards due to pressurized O_2, and allows for a passive system shutdown. Another safety advantage of employing onsite H_2 generation is that the safety risks associated with longterm H_2 storage (in the case of purchased hydrogen) are eliminated. This is especially important for remote manufacturing locations.

Applications for the M1 and M2 include pharmaceuticals and semiconductor manufacturing, as well as large-scale industrial heat-treating. In semiconductor applications, the generated H_2 can be used for oxygen scavenging or as a carrier gas. Potentially, the most promising outlet for large-scale H_2 generation lies in the fields of energy storage and fuel cells, where the modules can be installed into existing infrastructure. The generated H_2 can also be injected into methanation processes and integrated into the natural-gas grid or used for upgrading biogas.

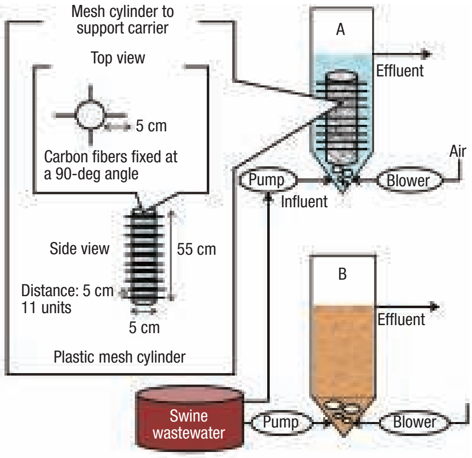
Carbon fibers enhance swine wastewater treatment

Takahiro Yamashita and colleagues at the Institute of Livestock and Grassland Science, National Agriculture and Food Research Organization (NARO, Tsukuba, Japan; www.naro.affrc.go.jp) have developed an aerobic bioreactor that can reduce nitrous oxide emissions by nearly 90% in the treatment of swine wastewater. The reactor uses an array of horizontal carbon fibers (CF) within the reactor column to support microorganisms.

A CF reactor with an effective volume of 10 L was tested against a conventional activated-sludge (AS) reactor (diagram), and was shown to achieve a 90% reduction in the released N_2O — a greenhouse gas with a global warming potential that is 300-times higher than that of carbon dioxide. The CF reactor also showed a "drastic" reduction in dissolved nitrogen.

The researchers evaluated the water quality of influent and effluent during 73 to 176 days operation after 72 days acclimation period. The removal efficiencies of the CF reactor were 96% for biochemical oxygen demand (BOD), 94% for suspended solids (SS), 93% for total organic carbon (TOC) and 90% for total nitrogen (TN). In the CF reactor, 156 mg/L of the dissolved inorganic nitrogen (DIN) was removed as NH_4-N, which left 14 mg/L DIN as NO_3-N; the DIN as NO_2-N was almost undetectable. In comparison, the removal efficiencies of the AS reactor were 94% for BOD, 76% for SS, 82% for TOC, and 26% for TN. In the AS reactor, 144 mg/L of the DIN was removed as NH_4-N, leaving behind 183 mg/L DIN as NO_3-N; the DIN as NO_2-N was also undetectable. N_2O and CH_4 emissions from the CF reactor were 42 g-CO_2 eq/m^3/d, while those from the AS reactor were 725 g-CO_2 eq/m^3/d.

NARO has now started to conduct tests with a demonstration-scale reactor with an effective working volume of 700 L, and the researchers are optimizing the reaction conditions for further scaleup.



(A) Aerobic bioreactor packed with carbon fibers (CF reactor)
(B) Aerobic bioreactor mixed with activated sludge (AS reactor)

Scaleup for a test facility to grow algae for biofuels

The New Energy and Industrial Technology Development Organization (NEDO, Kawasaki; www.nedo.go.jp) and partners IHI Corp. (Tokyo; www.ihi.co.jp), Kobe University (www.kobe-u.ac.jp) and Neo-Morgan Laboratory Inc. (NML; Kawasaki, all Japan; www.neo-morgan.com) have completed construction on an outdoor test site with 1,500-m^2 of pond surface area for further development work on the production of biofuels (including jet fuel) from algae. Located at Nanatsu Island, Kagoshima Prefecture in Japan, the facility will start up next month, and be used for developing a complete process for biofuel production, including the extraction process, working to lower production costs and enable stable mass-production. The facility is part of the NEDO project, "Development of the application technology of the strategic next-generation bio-mass energy."

The project will be looking at further developing the algae, *Botryococcus braunii*, which has a good potential for algaculture because of the type of hydrocarbons (HCs) it produces, and the fact that up to 86 wt.% (dry) can be long-chain HCs, which can be hydrocracked into fuels. The main drawback for this promising algae had been its slow growth rate.

But in 2013, IHI NeoG Algae LLC (a joint venture of IHI, Gene & Gene Technology (G> Suita, Japan) and NML operated a 100-m^2 outdoor facility in IHI's Yokohama site. With NEDO support, the company demonstrated the world's fasted growth rate for a *Botryococcus braunii* strain — 1,000 times faster than ordinary *Botryococcus braunii*. This fast-growing strain was first discovered by professor Taira Enomoto at Kobe University, further refined by G&GT, and improved by NML. The collaborations led to new strains with notable characteristics, such as larger algae bodies with improved floating performance.

CO_2 capture with permeable polymer microcapsules

Lawrence Livermore National Laboratory

A new type of CO_2-capture media based on permeable polymer microcapsules has been developed by teams of scientists at Lawrence Livermore National Laboratory (Livermore, Calif.; www.llnl.gov), Harvard University (Cambridge, Mass.; www.harvard.edu) and the University of Illinois-Urbana-Champaign (www.illinois.edu). The materials have several advantages over amine-based approaches to absorbing CO_2 from power-plant fluegas.

Using microfluidics techniques, the scientists produced microcapsules (photo, p. 12) that contain a liquid sorbent — sodium carbonate solution combined with a catalyst — that can absorb CO_2 quickly. The microcapsules are made from a highly permeable silicone polymer material that allows CO_2 molecules to pass through, but prevents the sorbent material from escaping. By forcing the sorbent to remain in small droplets, the microcapsules can maximize the surface area that contacts CO_2.

The permeable microbeads are inexpensive to make, easy to handle and produce minimal waste, the researchers say, and with encapsulated fluids inside, they allow users to combine the advantages of solid and liquid CO_2-capture media in the same system, while avoiding many of the environmental and corrosion issues posed by amine-based CO_2 capture.

Microcapsules have been used in a variety of products previously, including pharmaceuticals, cosmetics and food, but the scientists say their work is the first demonstration of the use of microcapsules in CO_2 capture. The project was detailed in a research paper published in a recent issue of *Nature Communications*. The researchers are working on enhancements that will allow scaleup of the technology.

Perfluorinated compounds may pose a risk to firefighters

Perfluorinated compounds — firefighting foams — such as perfluorooctane sulfonates (PFOS) have been used as fire suppressants, but some of them, such as perfluoroalkyl acids have been associated with serious environmental contamination. Also, several new fluorinated surfactants have been developed lately, and there has been concern over the effect of those substances on wildlife and on firefighters who are most exposed to them. However, several of those new compounds have not yet been identified and it may be very difficult to identify them.

Now, a team from the University of Queensland (Brisbane, Australia; www.uq.edu.au), Örebro University (Örebro, Sweden; www.oru.se), and Queensland University of Technology (Brisbane, Australia; www.qut.edu.au) has developed a method borrowed from medicine for identifying those substances in the blood of firefighters. The team compared the fluorinated surfactants found in the blood of 20 firefighters with compounds in the blood of 20 people who had not been exposed to firefighting foams.

The team ran the blood samples through the traditional quadrupole time-of-flight tandem mass spectrometry (QTOF-MS/MS) and has identified more than 3,000 organic and fluorinated compounds. However, when the team applied a statistical analysis to the data, a clear distinction appeared between the firefighters and the controls. The team found nine fluorinated compounds in the firefighters' blood, either exclusively or at much higher levels.

Only five of those compounds appeared in online chemical databases or in the literature interpreting the MS data. The team has tentatively identified the other four, unknown compounds as sulfonic acids analogous to PFOS.

Efficium allows for increased productivity (by up to 30% for truck tires) due to its impact on mixing and extrusion throughput, says the company. An additional benefit is added flexibility for compounders due to its silanization control and reformulation opportunities, without compromising on rolling resistance, wear and grip, the company adds.

NON-STICK POLYMERS

Researchers at Harvard University's Wyss Institute (Boston, Mass.; www.wyss.harvard.edu) have developed a surface technique that can prevent the formation of biofilms on medical surfaces. The approach, called liquid-infused polymers, enables polymers to soak up and store lubricating liquids that can move to the surface and prohibit bacteria from forming films. The the effect was studied using a solid silicone.

An electrochemical process to mimic photosynthesis

Photosynthesis is one of the best ways to convert carbon dioxide into renewable energy and at the same time, reduce the concentration of CO_2 in the atmosphere. In plants, there are two main steps in photosynthesis: First, water is split (via solar energy), generating a proton and releasing oxygen. The second step (Calvin cycle) is a dark reaction where CO_2 absorbed from the atmosphere is reduced to glucose. A proton is carried via NADPH (nicotinamide adenine dinucleotide phosphate-oxidase) and transferred to the Calvin cycle as a source of hydrogen and energy. A key step in the process is the hydrogenation of CO_2 to organic compounds.

Professor Jeffrey Chi-Sheng Wu, of the Dept. of Chemical Engineering, National Taiwan University (Taipei; ntu.edu.tw), has studied the photocatalytic hydrogenation of CO_2 by a novel twin reactor to mimic photosynthesis under light irradiation. His process is said to have a higher photoconversion yield of CO_2 than that achieved in a single reactor.

The twin reactor divides the hydrogen photocatalyst and the oxygen photocatalyst into two compartments using a membrane, which separates the H^+ ions and O_2 molecules, preventing a reverse reaction. Wu used Pt/$SrTiO_3$:Rh as the hydrogen photocatalyst and $BiVO_4$ as the O_2 photocatalyst. Iron is used as an electron mediator. Oxygen is released at one side of the reactor, while H^+ ions diffuse through the membrane to the other side. There, CO_2 molecules are reduced to hydrocarbons by the photocatalyst.

Wu investigated the diffusion of the Fe^{2+}/Fe^{3+} through a Nafion 117 membrane. The transfer rate of mediator ions was significantly larger than the photoreaction rate, indicating that the membrane did not delay the water-splitting reaction in the twin reactor. The H_2 generation rate reached 0.65 μmol/g·h and matched the H_2/O_2 stoichiometric ratio of water splitting. Wu found that the hydrogen-generation in the twin reactor system was the rate-limiting side. By using a twin reactor, the deactivation of Pt/$SrTiO_3$:Rh could be minimized due to the suppression of $Fe(OH)_3$ formation on the photocatalyst surface. ■

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- KURARAY
- LUBRIZOL
- METHENEX
- PPG
- PRAYON
- SHOWA DENKO
- SOLVAY
- STYROLUTION
- TECHNIP
- THERMO FISHER SCIENTIFIC
- W.R. GRACE

Plant Watch

Prayon to build food-grade sodium hexametaphosphate plant in Georgia

February 11, 2015 — Prayon S.A. (Engis, Belgium; www.prayon.com) plans to build a manufacturing plant for food-grade sodium hexametaphosphate (SHMP) in Augusta, Ga. Projected capacity of the new SHMP unit is 10,000 metric tons per year (m.t./yr). Supplementing an existing SHMP production site in Roches de Condrieu, France, the Augusta plant will double the company's global SHMP production capacity.

Showa Denko JV starts up alumina plant in Indonesia

February 9, 2015 — P.T. Indonesia Chemical Alumina, a joint venture (JV) owned by Showa Denko K.K. (SDK; Tokyo, Japan; www.sdk.co.jp) and PT Antam (Persero) Tbk., of Indonesia, has started commercial operations at its new alumina plant in West Kalimantan, Indonesia. The plant's production capacity for alumina is 300,000 m.t./yr.

Kuraray boosts production capacity for ethylene vinyl alcohol in Belgium

February 6, 2015 — Kuraray Co. (Tokyo, Japan; www.kuraray.co.jp) will increase the production capacity for ethylene vinyl alcohol copolymer (EVOH) resin at the Antwerp, Belgium site of EVAL Europe N.V., a wholly owned Kuraray subsidiary. The capacity increase will add 11,000 m.t./yr of EVOH production capability. The expanded facilities are expected to begin operations in late 2016.

Styrolution opens styrene-butadiene copolymer pilot plant in Antwerp

February 5, 2015 — Styrolution Group GmbH (Frankfurt am Main, Germany; www.styrolution.com) launched a styrene-butadiene copolymer (SBC) pilot plant in Antwerp, Belgium. An identical but scaled-down version of Styrolution's larger production SBC plant in Antwerp, which has a production capacity of 65,000 m.t./yr, the pilot plant will be used to conduct research, and to enhance specialty styrenics products.

Technip awarded contract for Qingdao ethylbenzene styrene monomer plant

February 3, 2015 — Technip (Paris, France; www.technip.com) was awarded a contract by Qingdao Soda Ash Industrial New Material & Technology Co. to provide the technology, engineering and services for an ethylbenzene styrene monomer (EBSM) plant to be located in Qingdao City, China. The plant's planned EBSM production capacity is 500,000 m.t./yr.

PPG plans capacity expansion for precipitated silica at Netherlands site

February 3, 2015 — PPG Industries, Inc. (Pittsburgh, Pa.; www.ppg.com) is increasing production capacity for precipitated silica at its manufacturing location in Delfzijl, the Netherlands, by more than 15,000 m.t./yr. The capacity expansion is expected to come online in 2016.

Arkema starts up thiochemicals plant in Malaysia

January 30, 2015 — Arkema (Colombes, France; www.arkema.com) has started up a new thiochemicals-production facility. Located in Kerteh, Malaysia, the new site produces methyl mercaptan for use as a synthesis intermediate in animal feed and dimethyl disulfide. Arkema's investment in the construction of this facility totaled €200 million.

Methanex starts up relocated Geismar methanol plant

January 26, 2015 Methanex Corp. (Vancouver, B.C., Canada; www.methanex.com) started up its methanol plant in Geismar, La. The plant's capacity is 1 million m.t./yr of methanol. The plant was relocated from the company's site in Punta Arenas, Chile.

BASF plans worldwide expansion of PVP production

January 22, 2015 — BASF SE (Ludwigshafen, Germany; www.basf.com) plans to invest up to €56 million in the expansion of its polyvinylpyrrolidone (PVP) value chain over the next four years. Through revamping existing plants in Ludwigshafen and Geismar, and introducing PVP technology at a site in Shanghai, the company will increase its global PVP production capacities by up to 6,000 m.t./yr.

Solvay building new hydrogen peroxide plant in the Netherlands

January 22, 2015 — Solvay S.A. (Brussels, Belgium; www.solvay.com) plans to build a new manufacturing and filling facility to produce hydrogen peroxide grades for the pharmaceutical industry. The new facility is located at Solvay's peroxide-production site in Linne-Herten, the Netherlands, and is expected to be completed in July 2015.

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Mergers & Acquisitions

Bentley acquires modeling software company Acute3D

February 10, 2015 — Bentley Systems, Inc. (Exton, Pa.; www.bentley.com) has acquired Acute3D (Valbonne; France; www.acute3d.com), a provider of software for reality modeling. Acute3D's software automates the generation of high-resolution, three-dimensional representations from digital photographs.

Thermo Fisher Scientific acquires Advanced Scientifics

February 5, 2015 — Thermo Fisher Scientific Inc. (Waltham, Mass.; www.thermofisher.com) has acquired Advanced Scientifics, Inc. (ASI; Millersburg, Pa.; www.asius.com) for $300 million. ASI designs, manufactures and delivers single-use systems and equipment for the preparation, processing, storage and transportation of biopharmaceuticals.

W.R. Grace to split into two separate companies

February 5, 2015 — W.R. Grace & Co. (Columbia, Md.; www.grace.com) has announced a plan to separate into two independent companies. The two companies, to be named prior to closing, will be "New Grace," comprised of Grace's Catalysts Technologies and Materials Technologies business segments, and "New GCP," comprised of Grace's Construction Products business segment and the Darex packaging business.

Johnson Matthey and Anellotech to jointly develop catalytic systems

February 4, 2015 — Anellotech Inc. (Pearl River, N.Y.; www.anellotech.com) and Johnson Matthey plc (London; www.matthey.com) will co-develop advanced catalyst systems for Anellotech's Catalytic Fast Pyrolysis Process for producing bio-based benzene, toluene and *para*-xylene.

FMC sells Alkali Chemicals business to Tronox for $1.64 billion

February 4, 2015 — Tronox Ltd. (Stamford, Conn.; www.tronox.com) has signed a definitive agreement to acquire FMC Corp.'s (Philadelphia, Pa.; www.fmc.com) Alkali Chemicals business for $1.64 billion.

Lubrizol acquires Brazilian coatings company EcoQuimica

February 2, 2015 — The Lubrizol Corp. (Wickliffe, Ohio; www.lubrizol.com) has acquired São Paulo-based EcoQuimica Industria e Comercio Produtos Quimica Ltda., a manufacturer and supplier of coatings technology. EcoQuimica is now part of Lubrizol Advanced Materials, reporting to the Performance Coatings business.

Solvay to divest Frankfurt-based refrigerant business to Daikin

January 30, 2015 — Solvay S.A. will sell its refrigerant and pharma propellants business based in Frankfurt, am Main Germany, to Daikin Industries, Ltd. (Osaka, Japan; www.daikin.com). The divestiture comes as Solvay increases focus on fluorine specialties and high-purity chemicals. ■

Mary Page Bailey

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Targeting Methane Emissions

New sensor, sealing and vapor-recovery technologies aim to reduce methane emissions

IN BRIEF

SOURCES OF METHANE EMISSIONS

INEXPENSIVE MONITORING

SEALING TECHNOLOGY

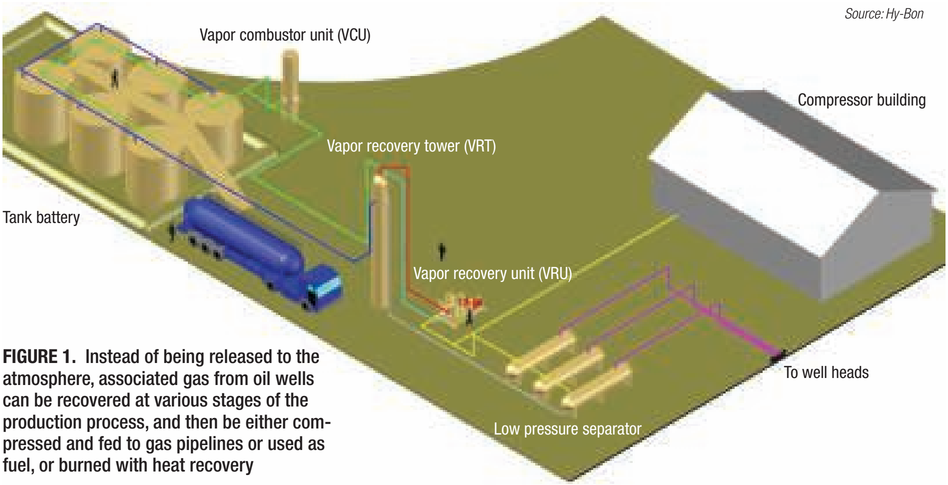

FIGURE 1. Instead of being released to the atmosphere, associated gas from oil wells can be recovered at various stages of the production process, and then be either compressed and fed to gas pipelines or used as fuel, or burned with heat recovery

On January 14, the Obama Administration announced a new goal to cut methane emissions from the oil-and-gas (O&G) sector by 40–45% from 2012 levels by 2025. The announcement builds on the foundation for further action laid out by the U.S. Environmental Protection Agency (EPA; Washington, D.C.; www.epa.gov), which in 2012 issued standards for volatile organic compounds (VOCs) from the O&G industry. Last April, EPA published five technical white papers* that focus on technical issues of compressors; "completions" (the process of getting a well ready to produce gas after it is drilled and fractured) and ongoing production of hydraulically-fractured oil wells; leaks; liquids unloading; and pneumatic devices.

Based on peer reviews and public input received, EPA will initiate a rule-making effort to set up standards for CH_4 and VOC emissions from new and modified O&G production sources, as well as natural gas (NG) processes and transmission sources. The rule is expected to be issued this summer, with a final rule ready by 2016.

Sources of methane emissons

Methane emissions accounted for nearly 10% of U.S. greenhouse gas (GHG) emissions in 2012, of which nearly 30% came from the production, transmission and distribution of NG. Although emissions from the O&G sector are down 16% from 1990 levels, the emissions are projected to rise more than 25% by 2025 without additional steps to lower them, according to The White House Office of the Press Secretary. Achieving the Administration's target would save up to 180 billion cubic feet of NG. The initiative would also support businesses that manufacture and sell cost-effective technologies to identify, quantify and reduce emissions.

One of the largest sources of methane emissions in the O&G industry is the flaring and venting of associated gas from oil-production facilities. The two main contributors are storage-tank vent gas (26.6 billion ft^3/yr) and well venting and flaring (18 billion ft^3/yr), according to Hy-Bon Engineering Company, Inc. (Midland, Tex.; www.hy-bon.com) — a major supplier of vapor-recovery technology (Figure 1). In the past, this associated gas has simply been vented at various places during the path from the well to the storage tank, says Inayat Virani, vice president, sales at Hy-Bon. This includes the gas released from the separator, as well as the vapors that accumulate in the headspace of the storage tank. In the U.S. alone, CH_4 vent-gas emissions are lost from storage tanks at the rate of 26.6 billion ft^3/yr, he says.

Vapor recovery units (VRUs) are one of the Best Management Practices of the EPA's Nat-

* www.epa.gov/airquality/oilandgas/whitepapers

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ural Gas STAR program,* and they capture 95% or more of hydrocarbon (HC) vapors being vented from storage tanks. These recovered vapors have a higher energy (Btu)content than pipeline-quality NG. Recovered vapors are thus more valuable than NG, and have multiple uses, including condensate recovery. "In a majority of cases, VRUs have a return on investment of about six months," says Virani.

Inexpensive monitoring

Although CH_4 is easily detected using infrared (IR) absorption spectroscopy and other techniques, the high costs of sensing technology have prevented routine applications for identifying and quantifying leaks — especially in remote, outdoor locations involving large numbers of wells and pipelines. Today there is a diverse group of leak detectors available, with IR cameras being state-of-the-art, says Ben Ratner, senior manager, Environmental Defense Fund (EDF; Washington, D.C.; www.edf.org). The problem is, such devices are very expensive (costing $80,000–100,000). Also, they tend to be less selective and are only able to find large leaks, he says. Because of this, the number of detectors being used in the field is limited, and then, only for periodic spot-checks. As a result, a leak could go undetected for many months. The challenge is to develop CH_4 monitors that are inexpensive, have good quality and ultimately can lead to reduced emissions, says Ratner.

With this in mind, EDF and seven O&G companies began the Methane Detectors Challenge in order to encourage the development of the next generation of sensors. "We want cheap, distributed sensors that can find leaks in realtime, thus changing the detection of leaks from months to minutes," says Ratner.

From the 22 teams submitting proposals in 2014, the following four most promising were selected by a team from EDF, industry and independent advisors to advance to round two:

- SensAir AB (Delsbo, Sweden) and Honeywell's RAE Systems (San Jose, Calif.; raesystems.com) for a leak detection system that integrates continuous sampling and a non-dispersive IR sensor for low parts-per-million methane detection
- The University of Colorado (Boulder; www.ucolorado.edu) for a metal-oxide sensor network on a single integrated circuit board
- Dalian Actech, Inc. (Dalian, Liaoning, China; www.dlactech.com) and Foller & Associates (San Francisco, Calif.; www.foller.net) for an IR laser-based system for continuous monitoring
- Quanta3 LLC (Longmont, Colo.; www.quanta3.com) for a CH_4-specific diode laser detection system

Next month, round two of the competition begins, in which these systems will undergo independent testing by the Southwest Research Institute (SWRI; San Antonio, Tex.; www.swri.org). By the end of this year, round three will begin, which involves demonstrations at industry pilot sites.

Meanwhile, last December, the U.S. Dept. of Energy (DOE; Washington, D.C.; www.energy.gov) announced the funding of 11 new projects to enable CH_4-emissions reductions through its Advanced Research Projects Agency-Energy (ARPA-E; www.arpa-e.energy.gov). As a part of ARPA-E's newest program, Methane Observation Networks with Innovative Technology to Obtain Reductions (MONITOR), $30 million has been distributed among 11 projects involving U.S. companies for developing new detector technologies.

For example, IBM (Yorktown Heights, N.Y.; www.research.ibm.com) has received $4.5 million to develop new, low-cost optical sensors and integrate them in a distributed sensor network. The sensors will use on-chip, tunable diode laser absorption spectroscopy enabled by shortwave IR silicon photonics technology. In another project, Palo Alto Research Center (PARC; a Xerox company; Calif.; www.parc.com) will use a variety of modified carbon nanotube (CNT) sensors to build (print) a sensor array that can identify, quantify and locate CH_4 leaks. And GE Global Research (Niskayuna, N.Y.; www.ge-globalresearch.com) will use a novel microstructured optical fiber as part of an IR spectroscopy system. The design will allow detection along the length of hollow optical fibers.

Sealing technology

As work on lower-cost leak detection progresses, another group of companies has been developing new sealing systems and gaskets that last longer and have reduced leakage. Some of these technologies have already been proven in other sectors of the chemical process industries (CPI), such as the chemical industry, where even miniscule leaks can lead to hazards or lost revenue. And others are being specifically developed to handle common leak sources in the O&G sector.

The Fluid Sealing Association (FSA; Wayne, Pa.; www.fluidsealing.com) has endorsed the EPA's goals for reducing CH_4 emissions, and has offered its support to help the Obama Administration reach its CH_4-reduction target. Normally, nobody thinks about seals unless they leak and a fire or explosion ensues, says FSA's technical director Henri Azibert. For example, nobody is going to dedicate a $10,000 VOC analyzer to monitor for leaks for a joint that uses a $10–50 gasket. One can look at any gasketed joint, and it might only be releasing a few parts-per-million of CH_4. However, because there are such large numbers of gasketed joints at a production facility, the accumulated emissions can become very significant, he says. "Aside from the environmental issues, that is lost product," says Azibert. Reducing these fugitive emissions can be achieved through the proper selection and installation of gaskets. In the end, such good practice is not only good for the environment, but it will save money, he says.

"The problem is, everyone wants to see a return on investment within three months instead of two to three years," says FSA's Henri Azibert

* For more information on the EPA's STAR program, see the longer version of this article at www.chemengonline.com

The sad part is, the O&G industry can actually benefit by being more conscientious. Good sealing solutions can save money in the long run, says Azibert. The problem is, everyone wants to see a return on investment within three months instead of 2–3 years. "That is being too short-sighted."

FSA has developed a calculator to help users determine the lifecycle costs for sealing systems. In some cases, a user can save millions of dollars over the lifetime of the system by using a $600 seal versus a $200 seal, says Azibert.

One area prone to fugitive emissions is compressors, which are widely used throughout the O&G sector, as well as across the CPI. Recent developments in sealing technology can greatly reduce — and even eliminate — CH_4 leakage from compressors.

The O&G sector uses two types of compressors, centrifugal and reciprocating. For centrifugal compressors, there are two sealing options. One uses oil as a barrier to seal the system. Because of the high rotational speeds involved, this type of seal needs to leak oil, otherwise the system will burn up due to frictional heat, explains Azibert. Although the oil is recycled, it is full of gas, and this gas has typically been vented in the past. The alternative is to use a dry seal, which uses gas for the sealing. FSA is working on an economic analysis of changing from wet to dry seals. The idea is that not only is the gas contained, but in doing so, it will save money over time, says Azibert.

In recent years — in part due to the efforts of EPA's STAR program — wet seals have actually become obsolete for centrifugal compressors, says Chris Kapp, head of Compression Technology Systems at Hoerbiger (Houston; www.hoerbiger.com). But because older machines are still in operation, some still need to be convinced to make the switch, he says.

For reciprocating compressors, the situation is totally different, because these machines use a system of valves and pistons to compress gas, similar to that used in car engines, instead of a rotating shaft. The piston rod-sealing system is one of the key factors determining the efficiency and reliability of the reciprocating compressor. With conventional packing, no matter how elaborate the design, there will always be a certain amount of leakage — as much as 500 to 1,000 L/h from a single packing, and a compressor can have up to eight packings, says Christian Hold, global product manager, Rings & Packing at Hoerbiger Ventilwerke GmbH & Co. KG (Vienna, Austria).

In 2008, Hoerbiger introduced its BCD packing technology, which incorporated a new seal ring. The packing features a split design that enables it to compensate for wear. As a result, leakage rates from this design are reduced by 2–3 times, and wear occurs uniformly. The lifetime of the packing has also been extended significantly — by 50% to even 800% in some cases. But it is still impossible to predict the integrity of such packing, so leakage rates are also impossible to predict, says Hold.

Source: Hoerbiger

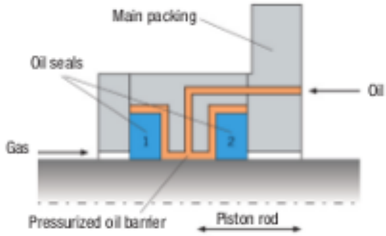


FIGURE 2. The XperSEAL (left) completely eliminates leakage from the piston rod of reciprocating compressors. It does this by means of a pressurized oil barrier (right)

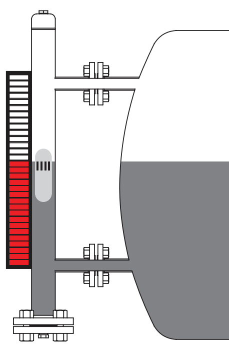
Now, Hoerbiger offers a completely new system tradenamed XperSEAL (Figure 2). Whereas leakage rates with BCD are cut in half, XperSEAL is inherently leak-free — true zero leakage — under both dynamic and static operations, says Hold. The sealing system also has the advantage that it does not require a packing cooling system, and it allows packing condition to be monitored continuously.

In XperSEAL, a pressurized volume of oil surrounds the reciprocating rod and is sealed by specially designed oil seal rings. This oil barrier prevents pressurized process gas from leaking along the rod. Another effect that occurs with using oil (as opposed to gas seals) is that the reciprocating motion of the rod makes it possible to "pump" oil after it has leaked out of the barrier, back into the barrier against the counteracting pressure gradient.

The first XperSEAL system was installed in the field in February 2012 at a CNG (compressed natural gas) refilling station operated by Öresundskraft AB (Helsingborg, Sweden). In this case, NG is compressed in four stages from 4 to 250 bars. Measurement showed that indeed CH_4 emissions were below the detection limit.

Other applications include a gas-compression unit at a NG gathering and treatment operated at NAM (Nederlandse Aardolie Maatschappij) B.V. — a JV of Shell Nederland B.V. and ExxonMobileNAM — in Assen, the Netherlands, where the new seal was specifically tested for its ability to prevent gas leakage. In another application — a compressor for a propane refrigeration unit in Egypt, the user was able to reduce operating costs by more than $100,000/yr by preventing loss of the valuable propane through leakage. All three of these field trials were presented at the 9th EFRC Conference (Sept. 11–12, 2014; Vienna, Austria). ■

Gerald Ondrey



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Process Control Provides A Holistic View

Integration between instruments and systems allows manufacturers to align process parameters with business performance

Source: Rockwell Automation

FIGURE 1. Modern DCS systems have plantwide capabilities, such as the PlantPAx modern DCS system installed at BASF in Ludwigshafen, Germany

IN BRIEF

TRANSPARENT INTEGRATION

SIMPLIFIED CONNECTIONS

INTERNET OF THINGS

As technological advances in instrumentation and control continue to progress, processors are beginning to realize that not only can their process control system keep a watchful eye on the process, but with the addition of some newer technology, it can also be used to determine the effect the process has on the entire enterprise. However, properly integrating the various instruments and systems, and distributing the data and information that would allow this holistic view can be a challenge. For this reason, more and more processors are asking for intelligent instruments and smart add-on systems that integrate flawlessly and securely with their distributed control systems (DCS), as well as a simple way for separate departments to view, analyze, interpret and use the collected information and data.

"Processors want more capabilities in their instruments, which can be addressed through hardware, software and technology that can be put inside protective envelopes and deployed in the chemical process industries (CPI)," says Donald Clark, vice president of global application consulting with Schneider Electric (Palatine, Ill.; www.schneider-electric.com). "This practice has generated more information than we've traditionally collected," explains Clark. "At the same time, processors are realizing that the plant process isn't just about making a product, but also about making a profit. In other words, there's more to examine than temperatures and pressures. There's a business here and they want to make sure that not only are the pressure and other process parameters under control, but that they are also making money via the controlled process. As a result, more demands from both the operational and business segments are being placed on control systems."

And, when you begin to extend process control into the business domain, he says, you can obtain business information in real-time. "Processors can't afford to wait until the end of the month for these critical numbers. They want to know right now how much energy the process is consuming, how much product they are making and if they are on target to meet production and profitability goals," says Clark.

Transparent integration of systems

In order to achieve this view of the business domain without departing from process control, it becomes necessary to integrate, nearly transparently, a large number of foreign instruments and systems under one larger infrastructure. So, providers of control systems are attempting to make this not only possible, but also seamless and simple.

As such, Schneider Electric offers its Foxboro Evo product. "It's like an integrating umbrella and hanging off it are controllers, maintenance systems, laboratory systems and the like," explains Clark. "And Foxboro EVO brings all these systems under one common infrastructure while providing a single human interface with schematics and diagrams and the ability to fetch information from any of these sources and integrate it into the ERP [enterprise resource planning], where it can be viewed, managed and administrated."

Foxboro Evo is referred to as an "enterprise control system" (ECS) that provides users with the opportunity to expand from process control into enterprise control with a single system through the available capabilities including a scalable network, cybersecurity hardening, unified control and safety, engineering tools, human/machine interface, enterprise historian and a maintenance dashboard.

Gordon Bordelon, industry solutions principal, chemicals, with Rockwell Automation (Milwaukee, Wisc.; ww.rockwellautomation.com) agrees that tighter integration between process and business networks is indeed a trend. "This allows information to be shared between the plant floor and the enterprise," he says. "This is not traditional chemical process control. Instead, it's blurring the line between process control and information technology (IT). Modern DCS and information systems now provide real-time process analytics to operations to empower process manufacturers to make more informed decisions resulting in improved profitability of production assets."

Bordelon says the DCS can no longer be an isolated operation. As organizations move toward gaining greater visibility into their operations, their need to establish a seamless flow of information from device to enterprise has become a requirement of a modern DCS. For this reason, the PlantPAx system from Rockwell Automation (Figure 1) is based on

FIGURE 2. Improved integration efficiency with smart device connections is simplified by the DeltaV S-Series Ethernet I/O Card

open communication standards, leveraging EtherNet/IP as its backbone. As a result, secure, realtime information can be made available throughout the enterprise for better business decisions. In addition, it allows the use of commercial, off-the-shelf products, smart field instruments and supports the adoption of the latest IT technology for automa-

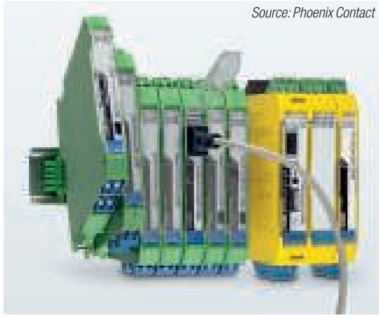


FIGURE 3. MACX signal conditioners meet the standards for functional safety in all phases of the product lifecycle, while also making integration and wiring easy

tion infrastructure, such as virtualization and industrial data centers.

At the same time, he says, many CPI processors are looking to standardize controls across the enterprise. "This means they would employ the same control system infrastructure, consistent applications and the same implementation methods across multiple plants," explains Bordelon. "As technology evolves, the technologies become easier to standardize, allowing processors to have common controls, standards, practices and management across many plants."

The PlantPAx modern DCS platform with open and common building blocks, sample code and

FIGURE 4. The Promass Coriolis density and mass flow family of flowmeters, as well as other flow and analytical instruments from this manufacturer, implement the ODVA EtherNet/IP Standard

configuration tools provides the groundwork for creating standards across an organization, says Bordelon. "We've created standard reference architectures for how networks are deployed. Our controller and I/O platform, which is the core of our modern DCS platform, has the ability to span multiple levels of a company's enterprise."

Simplified connections

While the sharing between operations and enterprise or between multiple plants opens up a host of business-optimization opportunities, getting the data from the instruments to the control system to facilitate such sharing can be a problem. For this reason, Emerson Process Management's (Austin, Tex.; www.emersonprocess.com) DeltaV digital control system offers I/O on Demand. Regardless of I/O type — traditionally wired I/O, Foundation Fieldbus, Profibus DP, DeviceNet, AS-ibus or even redundant wireless — users can add and begin using the information, natively and with far less engineering, design and fieldwork.

Most recently, says Dave Imming, vice president of product and services and marketing with the Process Systems and Solutions business unit of Emerson Process Management, the company has added Ethernet I/O cards (EIOC) to provide a platform to access data from intelligent field devices within the DeltaV system (Figure 2). Field devices capable of Modbus TCP, EtherNet/IP and EIC 61850 MMS protocols are all supported. The EIOC provides access to and control over the data of the device network by running control modules inside. In this way, PLCs, whole motor control or centers of single drives or switchgears can be controlled directly by the EIOC. The EIOC can be used to monitor or control directly any Ethernet protocol-based intelligent field devices. All the data coming into the EIOC can be used in control modules running inside the EIOC, allowing them to generate alarms when needed and be monitored by the operator. Each EIOC is capable of handling large amounts of data in up to 2,000 control modules received from a maximum of 256 physical and 256 logical devices. Up to 60 EIOCs can be added to the DeltaV I/O network, allowing freedom when it comes to segregation of networks. And, user-configurable IP addressing allows the EIOC to be used in almost any plant environment. The EIOC and the intelligent field devices must simply be on the same IP subnet to communicate.

"We see a lot of devices with Ethernet capability and this allows us to bring in a large amount of data via Ethernet ports and then bring things together, keep data relevant and get it to the right people," says Emerson's Imming.

Similarly, Emerson also offers DeltaV Virtual Ethernet I/O Card (vEIOC) for realtime, smart-device control and data integration. The vEIOC card resides in the I/O network in the DeltaV hierarchy. The card can be used with both online and offline systems. Modules needed to process the data from the field devices are configured, assigned and run in the vEIOC. In this

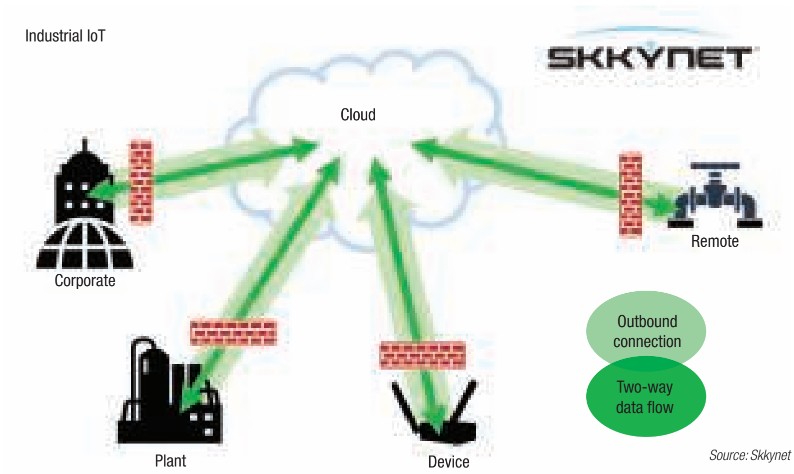


FIGURE 5. A cloud-based server will likely be the center of the industrial Internet of Things

way, the vEIOC is self-contained and does not need an external controller to process the data. Values can be read from another controller's control strategy via external references. Access to interface graphics, as well as alarming and history collection, is the same as any other module in the DeltaV DCS.

In addition to making it easier to get data from the devices into the system, the devices themselves are becoming easier to integrate. The ability to easily integrate is especially important when it comes to safety integrity level (SIL)-rated equipment. "Easy connection helps ensure that everything is working properly and meeting the safety regulations, as well as safety-related business goals," says Zachary Stank, product marketing specialist with Phoenix Contact (Harrisburg, Pa; www.phoenixcontact.com). "Processors don't need or want to spend a lot of time putting safety products into the DCS, so they want something that

THE INTERNET OF THINGS MEETS PROCESS CONTROL

The Internet of Things (IoT) is defined as the interconnection of devices within the existing Internet infrastructure. It is suggested that it will offer connectivity of devices, systems and services operating on a multitude of protocols. How this may translate into the future of process control is still up in the air. However, experts in control and computing have some ideas.

"Automation will look different in the future because we can push the intelligence of devices further into the process, because smart devices are getting smaller and cheaper," says Donald Clark with Schneider Electric. "In the past, automation was stuck on, like an appendage outside of the process, but with wireless and smart devices becoming smaller, we are able to take a sensor or controller and put it inside a reactor, pipe or pump and allow the equipment to not only report on temperature or pressure, but also provide diagnostics on itself, too. This means a pump could report on and control the process, but also administrate itself and send this information where someone can see it and act upon it.

"Putting automation directly inside pieces of equipment and collecting those data is where the Internet of Things is taking us," says Clark.

Already, some companies are taking steps that they say may redefine the future of process control. Skkynet Cloud Systems (Mississauga, Ontario, Canada; skkynet.com) has partnered with B+B SmartWorx (Ottawa, Ill.; www.bb-smartworx.com) to create intelligent networks that can collect, manage and analyze data generated by billions of sensors, transforming those data into actionable intelligence that lets companies make predictions and prescribe actions to cut costs, increase productivity or increase revenue.

The partnership is being launched with a focus on the IoT. B+B SmartWorx will provide a cellular router that collects raw data from devices and protocols and emits the data to Skkynet's Secure Cloud Service via the cellular network. From the Cloud, users — from operators to plant engineers to managers, analysts and customers — can access the information in a secure manner (Figure 5). "This is a more secure option than a VPN because the central plant is not attached, so there's no opportunity to attack," says Andrew Thomas, CEO with Skkynet. The service is capable of handling over 50,000 data changes per second per client, at speeds just a few milliseconds over Internet latency. Secure by design, it requires no VPN, no open firewall ports, no special programming, and no additional hardware.

integrates easily."

For this reason, Phoenix Contact developed MACX signal conditioners (Figure 3) with functional safety for processors who want to do analog signal conditioning but need to maintain an SIL rating. The signal conditioners have been developed and produced according to the standards for functional safety. In addition, they are available with maximum explosion protection and, with MACX Safety, users can integrate analog signals easily into the safety application, for intrinsically safe circuits in hazardous areas.

Another example of simplified integration of devices includes Endress+Hauser's (E+H; Greenwood, Ind.; www.us.endress.com) Promass Coriolis density/massflow family of flowmeters, as well as other E+H flow and analytical instruments, which implement the ODVA EtherNet/IP Standard (Figure 4).

"Intelligent devices continue to flourish by moving from supplying self-diagnostic information to providing operators/technicians with actionable problem-solving guidance," says Craig McIntyre, industry manager, chemical, with E+H.

The benefits of employing a Web-based device like the Promass Coriolis flowmeter are many, according to McIntyre, including a direct, two-way, high-speed digital communication of density, flow, volume flow, temperature and diagnostics/configuration information into an EtherNet/IP architecture environment in place of a traditional one-way analog/frequency/pulse I/O and associated controller scaling/integration programming.

The server-based Promass has an embedded Electronic Data Sheet and associated add-on profile, which are installed on the controller side, supporting rapid pre-configured integration for control and visualization. Pre-engineered faceplates for Promass are provided for rapid HMI visualization development. And add-on instruction exchanges data between each process variable located in the Promass and the faceplate installed on the display. The name of the specific add-on instruction becomes the link from the Promass to the faceplate on the graphic.

Further, says McIntyre, additional cost and risk reductions can be gained during the integration, field implementation and field service phases through the associated lifecycle-management system. Integrated application-engineering tools, factory-maintained device documentation and maintenance tools, and information-integrated support of engineering software implementations can bring increased information value and access to associated stakeholders.

"The use of server-based devices integrated into secure local and WAN implementations to reduce integration costs and facilitate remote management is increasing," says McIntyre.

And, this type of intelligent device, with its ability to seamlessly deliver data and information to a control system that ties process information to enterprise information in realtime, may mark the arrival of the Internet of Things in the process control industry. ■

Joy LePree

Circle 34 on p. 82 or go to adlinks.che.com/40273-34

Handling Bulk Solids

High-level detector has mercury-free tilt switch

The patent-pending BM-TSM tilt switch (photo) used for high-level detection of powders and bulk solids mounts on the top of bins and activates an alarm when material rises and tilts the switching mechanism by 15 deg. The shaft of the tilt switch can be custom made in lengths from 1 to 8 ft, to accommodate site-specific needs. It is available with either a paddle or sphere mount at the end of the shaft, and can be used with materials that have a bulk density of at least 15 lb/ft^3. Its simple mechanical design can be used as an alternative to a top-mounted rotary level indicator, and it is suitable for a wide range of solid materials in many industries, says the manufacturer. It can be installed through a 1.24-in. NPT process connection on the roof of the bin and sends an alert status to a horn, light or control panel.— *BinMaster, Div. of Garner Industries, Lincoln, Neb.*

www.binmaster.com

BinMaster

Magnetic pulleys help belt conveyors to separate metals

When used with conveyor belt systems, these permanent and electric magnetic pulleys (photo) automatically separate heavy tramp iron contaminants from the transported materials. Facilities can convert their belt conveyor into a self-cleaning magnetic separators by adding the pulley. These pulleys are constructed of steel center tubes with welded dividers to securely hold magnet stacks. Standard pulley models use powerful ceramic magnets in an axial interpole circuit. These magnetic pulleys are available in a wide range of diameters, and larger sizes and customization options are available. — *Eriez, Erie, Pa.*

www.eriez.com

Eriez

Ensure proper material flow with these vibrating hoppers

These fully assembled, self-contained vibrating hoppers are designed to promote the flow of any dry material. Capacities range from 3 to 100 ft^3 of storage. The Live Bin (photo) is designed to provide positive discharge of fine particles and fibrous or flaky materials, on a first-in, first-out basis, ensuring mass flow and eliminating material segregation. These hoppers can be used to discharge to any feeder or process line, or in applications where a surge bin is required. They are suitable for use in sanitary applications, says the company.— *Vibra-Screw, Totowa, N.J.*

www.vibrascrew.com

Vibra-Screw

This firm offers flow-properties testing services

To ensure sound, predictable operation of processes involving bulk solids, operators must have a thorough understanding of the bulk material's flow properties. Such insight is essential when designing silos, bins, hoppers, feeding systems, chutes, conveyors and more, and can help to identify the cause of poor flow, powder flooding and rate limitations, segregation issues and product non-uniformity. This company provides a wide array of testing services, to assess a material's cohesive strength, wall friction, internal friction, compressibility, permeability, angle of repose, density and more.— *Jenike & Johanson, Tyngsboro, Mass.*

www.jenike.com

This level-measuring device is undaunted by dust

Pulse radar is a proven technique for sensing bulk-materials level in silos and tanks, and is reliable and accurate when the space has a high level of suspended particles. The MP Series microwave-based, pulse-radar devices are used to determine the level of bulk solids in silos or tanks. The MP70 model has a measuring distance of up to 230 ft (70 m). Transmitting at a frequency of 26 GHz with a narrow beam angle of 8 deg, the MP Series radar de-

Note: For more information, circle the 3-digit number on p. 82, or use the website designation.

vices provide consistent, accurate measurements even in dusty environments, says the firm. — *Bindicator, Spartanburg, S.C.*
www.bindicator.com

Thermoformed belt makes this conveyor ideal for sanitary use

The Sanitary Belt Conveyor (photo, top left) is designed for bulk tablets, capsules, softgels and powders, as well as ingredients handled on regulated and over-the-counter pharmaceutical and nutritional-supplement manufacturing and packaging lines. Featuring a positive-drive, urethane belt, stainless-steel frame and components, open construction and other sanitary features, this belt conveyor eases cleaning, which reduces labor, speeds product changeover and increases uptime while improving equipment and product hygiene. Designed for conveying ingredients to blending and mixing operations, and finished products to packaging operations, the versatile conveyor comes in cantilever, flat and inclined configurations that can be mounted to the floor, mounted on casters or suspended. The belts can be designed with a flat surface or with a variety of shaped flights or flexible side walls to contain the product in the pockets during operation. The FDA-compliant belting is thermoformed to ensure a homogeneous and seamless belt, which reduces the risk of bacterial contamination and fouling. It can accommodate throughput from less than 2,000 lb/h to more than 60,000 lb/h. — *Symetix, Walla Walla, Wash.*
www.symetix.com

These devices provide the full range of level detection

The full family of Dynatrol bulk-solids level indicators (photo) provide probes that are well-suited for a diverse array of bulk solids materials. The DJ Series handles products ranging from low-density flakes and powders to heavy granules and pellets. The GJ Detector is constructed to handle problem applications that have a tendency to pack or bridge. The GSS sensor operates successfully with consistent results on difficult product applications (such as precipitated powders, fines, low-density powders and materials as light as 0.5 lb/ft^3. Side-wall-mount and suspended models are available. These rugged probes have no moving parts, ensuring long life in service. — *Automation Products, Dynatrol Div., Houston*
www.dynatrolusa.com

Bulk-bag filling station has a variety of design features

The stainless steel, sanitary Bulk Bag Filler (photo) fills bags by weight. It includes an integral metal detector/separator that removes tramp metals as the material enters the filler,

and then ejects the collected metals through a chute. The filler frame uses a patented "twin centerpost" design, which is said to maximize strength and improve accessibility to bag hooks. The height of the fill head is adjustable, to allow for bags of many sizes to be used, and an inflatable cuff forms a high-integrity seal to the bag inlet spout. An automated vibratory deaeration and densification system maximizes capacity and stabilizes the bag for storage and shipment. This bulk-bag filler has received USDA acceptance, is constructed of Type 316 stainless steel and finished to sanitary standards, and is configured with full-length forklift tubes, allowing it to be easily moved throughout the facility.— *Flexicon Corp., Bethlehem, Pa.*
www.flexicon.com

Radar level-detection probe is undaunted by uneven surfaces

The Optiwave 6300 C radar instrument provides accurate measurement of solids level in silos, hoppers, bulk storage containers, and on conveyor belts, and is said to be especially well-suited for measuring the uneven surface of silo contents. The patent-pending drop form of the plastic antenna generates a smaller beam angle (2 deg) compared to conventional antennas, eliminating the need for an antenna-aiming kit to amplify the reflected signal. The drop form also helps to minimize crusting or dust buildup on the antenna, making it ideal for applications involving materials with high dust potential, such as mineral powders, granulates and wood chips. Users can choose from a 3-in.-dia. antenna made from polypropylene or polytetrafluoroethylene, or a 6-in.-dia. (DN150) antenna made from polypropylene. Conventional stainless steel horn antennas up to 6 in. (DN150) are also available. An installation wizard and comprehensive help capabilities, available in nine languages, ease setup and startup. — *Khrone, Inc., Peabody, Mass.*
www.us.krohne.com

Lightweight, flexible conveying hose resists abrasion

Norplast PUR 387 hoses (figure) provide good abrasion resistance,

Norres Schlauchtechnik

making them well-suited to handle high flowrates of extremely abrasive solids, such as sand gravel, grain, refuse glass and chips. The abrasion resistance of this hose is 2.5 to 5 times higher than comparably sized hoses of most rubber materials, and is about 3 to 4 times higher than those constructed from most soft polyvinylchlorides (PVC), says the company. The smooth interior helps to optimize flow. A sister product — the Norplast PUR-CU 387 AS — features metallic grounding wire and a permanently antistatic polyurethane inside liner, which extends the scope of applications by making the hose suitable for use in areas exposed to potential explosion hazards.— *Norres Schlauchtechnik GmbH, Gelsenirchen-Schalke, Germany*
www.norres.com

Protect powder-handling systems from explosion risk

A full line of explosion-protection solutions offers protection for facilities handling potentially explosive bulk solids. This company offers a wide array of ATEX-certified explosion vents, flameless explosion-venting systems, explosion-suppression systems, explosion-isolation systems, and explosion detectors. The company also offers state-of-the-art explosion-testing services to evaluate materials in accordance with ASTM and ISO procedures. — *Fike Corp., Blue Springs, Mo.*
www.fike.com

Particulate-monitoring device is approved for hazardous duty

Auburn Systems

The Auburn U3400H is a two-wire, loop-powered, dynamic-range par-

ticulate monitor for both high- and low-temperature applications using HART protocol (photo). It is designed for use in particulate-matter monitoring applications that require hazardous location certification. It is designed for emission monitoring and process flow applications (such as bag-leak detection, or monitoring flow increases or decreases) for which a continuous 4-20-mA signal is needed. The HART protocol allows for bi-directional communication with the unit for remote access and control. The U3400H is designed to be wired directly to a PLC, DCS, data logger or any control device capable of providing the 24-V loop power while simultaneously receiving the continuous 4-20-mA signal. — *Auburn Systems, Danvers, Mass.*
www.auburnsys.com

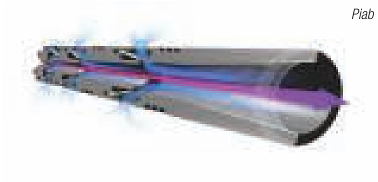
Vibratory feeders convey bulk solids smoothly

Available in electric or air-operated models, these heavy-duty vibratory feeders are designed with above-, below- or side-mounted drives and

can be arranged for base mounting or overhead suspension (photo). Feeders come in a range of vibrating trough lengths and special designs are available. The company's optional BPS Inertial Isolation System is designed to eliminate the transfer of vibratory energy to support structures and buildings.— *Best Process Solutions, Brunswick, Ohio*
www.pbsvibes.com

This vacuum technology uses the venturi effect

Vacuum conveying technology is widely used to provide gentle transport of dry bulk solids and



powders in a range of applications. This firm offers a family of vacuum pumps and vacuum generators, based on patented, multistage Coax technology. The vacuum pump (photo) uses compressed air as the input, and through a venturi effect, is able to generate 22-in.-Hg vacuum, while driving air volumes (std. ft^3/min) that are three times the volume of the compressed air inlet. Through the use of multiple stages, high vacuum is generated as the air flow is ramped up. This pump has no electric parts, which reduces maintenance and ensures long life and inherent safety in dusty or hazardous environments. — *Piab USA, Hingham, Mass.*
www.piab.com

This vibratory separator can handle wet or dry materials

The Finex Separator vibratory separator is designed for accurate grading, scalping or sizing of wet or dry materials, and can produce up to five different size fractions in a single operation. Compared with traditional spring-suspension separators, these systems are said to have improved accuracy, capacity, noise levels and flexibility in terms of system upgrades. Four sizes are available: 30-, 40-, 48- and 60-in. dia. — *Russell Finex, Inc., Pineville, N.C.*
www.russellfinex.com

Seal designs and more for powder handling are offered

Maintaining a proper seal against dry particulates or chemicals can present challenges. This company offers a variety of seal designs and materials, such as quick connect and disconnect seals for hoppers, bulk-bag filler systems and transfer cars, inflatable follower plate and drum-filling seals, FDA-compliant thermoplastic elastomer compression gaskets to seal doors and other machine closures, and more. — *Pawling Engineered Products, Pawling, NY.*
www.pawlingep.com ■

Suzanne Shelley

New Products

Tank-cleaning nozzles that can handle lower flowrates

The expanded HydroWhirl Poseidon line of tank-washing nozzles (photo) now includes lower flowrates. The nozzles can now handle flowrates ranging from 4.45 to 26.3 gal/min. The smaller-sized nozzles are designed to fit through openings as small as 2 in., while maintaining a slow and controlled rotation speed. Complete 360-deg omnidirectional coverage allows for increased cleaning efficiency, and the nozzles' slow-spinning spray and longer spray dwell time on the target surface increase impact when compared to conventional rotating designs. Fluid-driven and lubricated, these rotating tank-cleaning nozzles are constructed of corrosion-resistant polytetrafluoroethylene (PTFE) material and are ideal for harsh chemical environments. — *BETE Fog Nozzle, Inc., Greenfield, Mass.*
www.bete.com

A fully temperature-compensated handheld pressure calibrator

The new HPC40 Series handheld pressure calibrator (photo) is said to be the world's first milliamp-loop calibrator that is fully temperature compensated from –20 to 50ºC, enabling it to deliver the same accuracy whether measuring pressure, current, voltage or temperature. Suitable for calibrating pressures ranging from vacuum to 15,000 psi, with an accuracy of 0.035% of reading for all ranges, HPC40 instruments are designed for process-control applications, such as verification or calibration of pressure gages, transducers, transmitters, pressure switches and safety valves. A single HPC40 Series device can typically replace several gages or calibrators. — *Crystal Engineering, San Luis Obispo, Calif.*
www.crystalengineering.net

These industrial-gas pressure regulators have three outlet ports

The T39 Series of industrial-gas pressure regulators (photo) incorporates three outlet ports within a single regulator, allowing for more versatility, as well as potentially simplified piping layouts. T39 Series regulators are available with a choice of seat materials, in six spring-pressure ranges from 0–30 to 0–225 psig. The regulators are equipped with 302 stainless-steel diaphragms, and nickel and stainless-steel housings are available on request. Each regulator comes with a four-seat valve-disc block, which can be rotated to provide a fresh valve-disc sealing surface, with spare valve discs provided. — *Marsh Bellofram Corp., Newell, W. Va.*
www.marshbellofram.com

Use this wireless device to remotely monitor storage tanks

The TankLink 95 (photo) is a wireless monitoring device for chemicals in vented and unvented storage tanks in hazardous locations, providing access to tank data (such as critical level and daily usage history) remotely. The TankLink 95 utilizes 3G and 4G mobile networks to monitor tank data, preventing personnel from having to enter hazardous areas (such as those where flammable vapor and gases or other ignition threats are present) to collect tank information. — *Telular Corp., Chicago, Ill.*
www.tanklink.com

This new SmartBob features horizontal mounting

The SmartBob HM (horizontal mount) is a weight-and-cable-based level sensor that can be mounted on the side of a bin, tank or silo. The SmartBob HM features a rigid extension to install on the side of the bin. Precise level measurements are taken at predetermined time intervals at a location directly below the probe to continuously monitor the inventory of material inside of the bin. The device's continuous level sensor works like an automated tape measure, but eliminates the need to climb bins for manual measurements. It is listed for Class II, Groups E, F, & G and enclosure types NEMA 4X, 5 and 12, ensuring the sensor is safe to use in locations where combustible dust may be present. — *BinMaster, Lincoln, Neb.*
www.binmaster.com

A pod system that eliminates the need for hand dosing

This modular "pod" system (photo, p. 38) is a self-contained, batch weighing and metering system that delivers

BETE Fog Nozzle

Crystal Engineering

Marsh Bellofram

Telular

Ingredient Batching Systems

dry powder ingredients directly into a vacuum-conveying line with high accuracy and low cost, according to the company. The new pod system is suitable for the food and pharmaceutical industries, where a product may have a number of different ingredients that traditionally have been dosed by hand. The system can be made of one or any number of pods linked together via a common vacuum conveying line and a central controller. The ingredient is loaded onto each pod from flexible intermediate bulk containers (FIBCs) or sacked product. The system is sealed, so airborne dust is eliminated. — *Ingredient Batching Systems, London, U.K.*
www.ingredientbatchingsystems.com

Rugged cellular router offers broadband wireless connectivity

The Ruggedcom RX1400 (photo) is a multiprotocol intelligent node that combines Ethernet switching, routing and firewall functionality with various WAN connectivity options. The device is IP40 rated, does not use fans for cooling, operates continuously within a –40 to 85°C temperature range and comes with a rugged metal housing that supports DIN rail, panel or rack mounting. The Ruggedcom RX1400 provides a high level of immunity to electromagnetic interference, heavy

Siemens AG

electrical surges, extreme temperature and humidity for reliable operation in harsh environments. — *Siemens AG, Munich, Germany*
www.siemens.com

A float-level transmitter with many fittings options

The NML-308 is a miniature, synthetic float-level transducer suitable for level measurement in vessels up to 48 in. tall. The floats are made from PTFE and the tubes are 316

stainless steel. The fittings are available in PTFE, polyethylene (PE), polypropylene (PP) or polyvinyl chloride (PVC). The transmitted level signal is converted to a 4–20-mA analog signal via a remotely mounted DIN rail transmitter. — *Kobold Instruments Inc., Pittsburgh, Pa.*
www.koboldusa.com

A sealless thermoplastic pump for open tanks and sumps


Michael Smith Engineers

The new range of ARBO sealless, thermoplastic immersible centrifugal pumps (photo) are ideal for situations where metal pumps could suffer from the effects of corrosion. ARBO single-stage immersible pumps can handle capacities up to 300 m^3/h at differential heads up to 80 m and liquids with viscosities up to 100 cP. The pumps can be supplied in PP as standard, as well as the options of high-modulus PE, polyvinylidene difluoride (PVDF) and PTFE for applications where more corrosive liquids, higher temperatures, or higher solid concentrations are involved. — *Michael Smith Engineers Ltd., Woking, Surrey, U.K.*
www.michael-smith-engineers.co.uk

A space-saving digital indicator with many functions

The model DI32-1 (photo) is multifunctional and, with its small dimensions (48 × 24 × 52 mm), ideal for applications with limited mounting space. The multifunction input of the DI32-1 digital indicator offers 23 input configurations. Thus, the measured values from transmitters with current

WIKA Alexander Wiegand


and voltage signals, as well as those from resistance thermometers and thermocouples can be displayed. The instrument is also suitable for frequency and rotational-speed measurements, and, in addition, as an up/down counter. The indicator also records minimum or maximum values, enables the linearization of sensor values with up to five programmable points and has a tare function. — *WIKA Alexander Wiegand SE & Co. KG, Klingenberg, Germany*
www.wika.com

Analyze steels in the field, even for hot-tapping applications

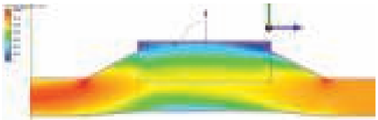
The Belec Compact Port (photo, p. 40) is a versatile mobile spectrometer currently going through the evaluation process with a Fortune-500 oil-and-gas organization for the detection of

sulfidation corrosion in hot applications. The Compact Port incorporates features required by oil-and-gas inspection professionals. The system has ultraviolet (UV) probes to detect C, P, S, B and N in Duplex stainless steels, with probe lengths from 3 to 5 m for hard-to-test areas. The system has temperature-stabilized optics for stable low-level detection limits. The system detects low levels of carbon in stainless or low-alloy steels while meeting the requirements of API 578 and API 939-C in the field, and is capable of conducting carbon-equivalency calculations at 350°F for hot tapping applications — *Innovated Analytical Solutions LLC, Bremen, Ala.*
www.steelanalyzer.com

CFD optimizes this modular range of blowing seal valves

One of the problems faced with blowing-seal type rotary valves is to maintain the air velocity between the valve and the conveying pipe while still achieving a good rotor pocket purge. Designers at this company have solved this problem using computational fluid dynamics (CFD) software, in conjunction with a standard CAD package to determine the profile that would guarantee minimum pressure loss and maximum pocket purge. One of these CFD-designed profiles was chosen (photo) for the comany's new modular valve range. There is hardly any drop in air velocity during conveying with the smoother airflow through the valve, which results in improved rotor life and efficient pocket purging. This in

Rota Val



turn leads to increased valve life, because high velocity-wear erosion is reduced by the fuller, smoother airflow. — *Rota Val Ltd., Chippenham, Wiltshire, U.K.*
www.rotaval.co.uk

A highly concentrated additive that prolongs biodiesel shelf life

Introduced in January, Baynox Ultra is a highly active liquid stabilizer specially designed for biodiesel made from polyunsaturated fatty acids, such as soybean and sunflower methyl esters. This easily metered additive contains a balanced blend of highly active antioxidants and a chelator, dissolved in a "green" solvent. Thanks to the high active-ingredient content of over 40%, 200 to 500 ppm of Baynox Ultra is generally sufficient to ensure a reliable shelf life for biodiesel. As the product also remains liquid to –5°C, storage

tanks and pipes do not need to be heated in winter. Another additive (Baynox Cargo), designed to stabilize biodiesel tanks in ships and ports, has also been introduced. — *Lanxess AG, Cologne, Germany*
www.lanxess.com

Safety and diagnostic features enhance this flowmeter line


Emerson Process

The new Rosemount 8700M Magnetic Flowmeter line (photo) provides enhanced safety for hazardous-area applications, along with intelligent diagnostics. Glass feed-throughs transmit signals between isolated compartments of the transmitter enclosure, providing the most effective barrier for safety and reliability. The all-welded sensor design and dual-compartment transmitter housing keep critical components isolated from environmental hazards — a leading cause of electronics failures. Enhanced diagnostics, including Smart Meter Verification and the new Electrode Coating Detection provide users with more information than ever before about the flowmeter, installation and process, enabling more informed decision-making, easier identification of process issues, and simplified flowmeter verification. The Electrode Coating Detection diagnostic identifies coating on the electrode before the sensor signal is compromised, helping to prevent inaccurate flow measurement. — *Emerson Process Management, Shakopee, Minn.*
www.rosemount.com/8700

A new full-stroke, integral piston diaphragm model

This manufacturer of air-operated double-diaphragm (AODD) pumps has recently introduced its 76-mm (3-in.) size Full-Stroke Integral Piston Diaphragm (FSIPD). The new FSIPD


Wilden

(photo) is ideal for use in the company's Saniflo FDA pumps, as well as its Original, Advanced and Advanced FIT series of AODD pumps. These 3-in. diaphragms are said to be well-suited for hygienic applications because they are constructed of food-grade Wil-Flex (Santoprene), and unlike conventional diaphragms, the integral piston is completely encapsulated within the TPE material, meaning there is no outer piston that can trap fluid and particles. The diaphragms withstand temperatures from –40 to 107°C, and meet the requirements of FDA CRF 21.177, EHEDG and 3A. — *Wilden, part of PSG, a Dover Co., Grand Terrace, Calif.*
www.wildendiaphragms.com ■

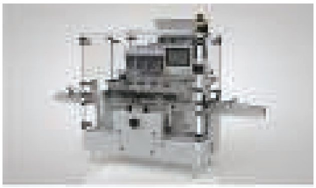
Gerald Ondrey and Mary Page Bailey

INTERPHEX

Newark Wire Cloth

Rigaku Raman

NJM Packaging



Highlighting technology and innovations in the sectors of pharmaceutical and biopharmaceutical manufacturing, Interphex 2015 is taking place April 21–23 at the Jacob Javits Convention Center in New York City. Over 12,000 professionals are expected to visit the event's workshops, networking sessions and exhibit hall. The following product descriptions represent a small selection of the more than 600 exhibitors who will be showcased at Interphex 2015.

These strainers handle both coarse and fine-particle filtering

The SaniClean line of strainers are specifically designed for use in processing applications where cleaning is critical, such as those requiring coarse straining or fine-particle filtration in the pharmaceutical, food, dairy and beverage industries. The strainers are suitable for both continuous production cycles and small-batch runs. A variety of capacities are available, ranging from low creeping flowrates to high-volume production outputs. The strainers can be integrated into existing or new piping configurations. The standard material of construction is 316L stainless steel (photo), but other corrosion-resistant alloys are available. Booth 3370 — *Newark Wire Cloth Co., Clifton, N.J.*
www.sanicleanstrainers.com

Positively validate materials with this handheld Raman analyzer

The Progeny line of handheld Raman analyzers (photo) is designed for quick, non-destructive material validation, allowing for immediate rejection of non-conforming materials and fewer quarantined shipments. The raw-material identification provided by Raman spectroscopy helps to ensure that manufacturing standards are met, and that final products meet specifications and comply with regulations. With a design inspired by smartphones, Progeny analyzers feature touchscreen user interfaces, an integrated digital camera and large-sized display buttons. Also included are a 1,064-nm excitation laser and a built-in, adjustable nose cone, which allows measurement even through thick polymer materials or dark glass. Booth 2878 — *Rigaku Raman Technologies Inc., Wilmington, Mass.*
www.rigakuraman.com

This compact tablet counter accommodates four modules

The Cremer Model CFS-622*4 four-module tablet counter (photo) can count almost any kind of tablet or capsule, and fill almost any kind of plastic or glass bottle, including those with round, oval or rectangular shapes. The small-footprint design allows for simple integration into new or existing lines, and its transparent enclosure provides accessibility. A vision-inspection feature allows for the detection of broken and rogue tablets; when a faulty container is detected, the CFS-622*4 will reject it. Other standard features include a central product hopper, a touchscreen control panel and a servo-driven feedscrew. A central dust-extraction mechanism, a product eject system and an ionizer to eliminate static electricity are optional add-ons. Booth 2353 — *NJM Packaging, Lebanon, N.H.*
www.njmpackaging.com

This isolator system features a fast decontamination process

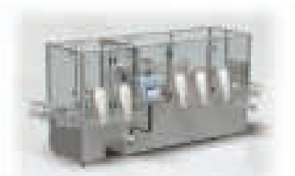
The Pharmaceutical Safety Isolator L-Flange (PSI-L) system is a modular isolator system outfitted with an L-shaped flange. The unique flange design enables equipment to be changed quickly, and the possibility of using an empty flange plate provides maximum flexibility. The system's short (less than 20 min) decontamination cycle and a return air filter create a sterile environment for aseptic or highly active pharmaceutical products. Booth 3055 — *SKAN AG, Allschwil, Switzerland*
www.skan.ch

Constant-pressure processors that ensure uniform handling

This company's Microfluidizer family of high-shear fluid processors enables uniform particle-size reduction, bottom-up crystallization and efficient cell disruption, and can be used in the development of nano-enabled

Boccard Life Sciences

Adaptive Manufacturing Technologies



Optima Packaging Group

Watson-Marlow Pumps Group

medicines, chemicals and consumer products. The key to the Microfluidizer's uniform material-handling capability is its ability to maintain a consistent process pressure within the system. Suitable for a variety of applications, including both laboratory use and full commercial production, these processors provide size reduction and disruption in the sub-micrometer range, and numerous scaleup options are available. Booth 1653 — *Microfluidics International Corp., Westwood, Mass.*
www.microfluidicscorp.com

Forming, filling and sealing for multi-product manufacturers

The QuickPouch Vertical (photo) is a compact, customizable machine designed to form, fill and seal pouches. The system can handle package sizes of up to 6 in. in width and 9 in. in height. The machine's simple design is advantageous to manufacturers with multiple products; changeovers are simple, taking as little as 15 min. The QuickPouch Vertical is available with many options, including printing, automatic loading, liquid or powder filling, die-cutting and more. Applying a hot die to imprint the pouch form, the cycle-on-demand system is equipped with time, pressure and monitoring functions. Pouch materials include foil laminate, paper laminate and plastic laminate. Booth 3857 — *Adaptive Manufacturing Technologies, Ronkonkoma, N.Y.*
www.amtautomation.com

A compact filling and closing machine with 10 filling positions

This company's H4 filling and closing machine (photo) can process nested vials, syringes and cartridges, and also allows for the pre-manufacture of certain modules, providing cost savings and flexibility for a number of diverse applications. Even within a compact footprint, the H4's transport system achieves a high output rate of 24,000 objects/h, which can be expanded to 36,000 objects/h with certain retrofitting options. The H4 comes equipped with a ten-position filling system. For filling flexibility and simple format changes, rotary-piston pumps, as well as peristaltic or time-pressure filling systems can be added at any time. Further customizations are available through the addition of upgraded in-process controls and the insertion of vacuum stoppers. Booth 3103 — *Optima Packaging Group GmbH, Schwäbisch Hall, Germany*
www.optima-packaging-group.de

Safeguard sensitive connections with this tool

The BocLock intelligent connection system (photo) safeguards process connections in mechanical and automated systems, and is specifically designed for flow-transfer panels with frequent connections. Suitable for very sensitive processes, the system features a multi-colored indicator light that continuously informs the operators of the connection status. This includes notifying the operator if the connection is awaiting action, or if the connection is dirty, clean or incompatible. The BocLock's stainless-steel construction allows for in-situ cleaning, and the system comes equipped with an integral passage with a standard hygienic seal. Booth 3168 — *Boccard Life Sciences, Inc., Sugar Land, Tex.*
www.boccard-bls.com

Cloud-based temperature and humidity monitoring

The OneVue intelligent platform is a cloud-based system that monitors critical temperature and humidity data. With its responsive design, the OneVue platform can be configured on any tablet, smartphone, laptop or desktop computer. Alert routing rules can be set up to deliver notifications via email, text message or phone. According to the company, the platform is unique in that the data generated by sensors are tied to the room, physical equipment (such as refrigerators) or inventory (such as pharmaceuticals) being monitored, rather than to the sensor itself, creating historical data trails. Booth 1015 — *Primex Wireless, Lake Geneva, Wisc.*
www.primexwireless.com

Single-use fluid-path components designed for bioprocessing

This company's BioPure family of single-use fluid-path components is manufactured specifically for bioprocessing applications, and includes the following products: BioClamp plastic quick-release tri-clamps (photo); Bio-

Barb hose-tail to tri-clamp adaptors; FlatBioEndCap connectors for endcaps, BioEndCaps, which are designed to permanently terminate a disposable manifold until an in-process new sterile connection is to be made; BioY equal-barbed Y-connectors; and BioValve restriction flow-control and shutoff valves for silicone tubes. These fully traceable components are intended to emulate over-molded products. Featuring full-through bore diameters, these components are designed to reduce dead spots in processes. Booth 2833 — *Watson-Marlow Pumps Group, Wilmington, Mass.*
www.watson-marlow.com

Filter bags designed with safety and security in mind


Sefar

This company's Pharma-Grade Filter Bags (photo) for fluid-bed dryers are constructed in a dedicated cleanroom to ensure high standards of purity and detail. The bags have been developed to avoid possible contamination from staple fibers. A microporous membrane laminated on polyester or polytetrafluoroethylene (PTFE) provides efficient filtration. An antistatic version of the bags is available, with an incorporated high-conductivity stainless-steel matrix, which provides excellent explosion protection. Booth 2137 — *Sefar, Inc., Depew, N.Y.*
www.sefar.com

These dry granulators have sensor-controlled rollers

BRC 25 dry granulators (photo) process powders into free-flowing granules. Fed via a dosing unit, the powder is compacted between two rollers and discharged as flakes. The


L.B. Bohle Maschinen + Verfahren

gaps between the rollers are controlled and monitored with sensors, and can range from 1 to 6 mm. Sensors also monitor the forces on the rollers. Below the rollers is a chopper unit, where the flakes are processed into granules. A built-in conical sieve with exchangeable sieve units allows control over particle size. Within the machine, the axes are mechanically stable so that elastic deformation is prevented, eliminating the need for complete axis control. Booth 2811 — *L.B. Bohle Maschinen + Verfahren GmbH, Ennigerloh, Germany*
www.lbbohle.de

Achieve precise wet milling and emulsifying with this system

The HV model combination emulsifier and wet mill is designed for precise emulsifying in a single pass, and is capable of wet milling some active pharmaceutical ingredients to the 10–20 µm range. Operating at an extremely high rotational velocity, tooling tip speeds of up to 70 m/s are achieved, providing more than 55 times the shear-energy input compared with conventional rotor-stator systems, says the company. This performance envelope fills the gap between existing rotor-stator technologies and high-pressure homogenizers. The HV emulsifier and wet mill is available in three models with scalability ranges for laboratory, pilot and production volumes. Booth 1653 — *Quadro Engineering, Waterloo, Ontario, Canada*
www.quadro.com ■

Mary Page Bailey

Steel Corrosion

Department Editor: Scott Jenkins

Corrosion of steel is a key concern in many industrial settings, both from an asset-management perspective and from a safety perspective. The following briefly describes corrosion mechanisms for various classes of steel, and provides information on the corrosion resistance of these ubiquitous iron-based alloys.

Carbon steels contain only iron and carbon, with carbon making up between 0.002 and 2.1 wt.%. Low-alloy steels contain a variety of other elements added to achieve desired properties of corrosion resistance, strength, formability and other characteristics. Steel is classified as stainless steel if its chromium content is at least 10.5 wt.%, and its carbon content is less than 1.20 wt.%, as defined in ASTM Standard A240 (ASTM International; West Conshohocken, Pa.; www.astm.org).

Iron oxidation

Steel corrosion is an electrochemical process requiring the simultaneous presence of water and oxygen. The anode reaction involves the formation of Fe^{2+} ions and the release of electrons, while the cathode reaction involves a reduction of dissolved oxygen, with water as an electrolyte.

$$Fe^{0} \longrightarrow Fe^{2+} + 2e^{-}$$
$$O_2 + 2H_2O + 4e^{-} \longrightarrow 4OH^{-}$$

Iron ions react with the hydroxide to form iron hyroxides [such as $Fe(OH)_2$], which react further with oxygen to give $Fe_2O_3{\cdot}H_2O$ (rust). The presence of acids and chlorides accelerates the corrosion process.

Stainless steel

The chromium in stainless steels allows the generation of a complex chromium-oxide surface layer that resists further oxidation (passive layer). The chromium-oxide layer is thin (microns) but tough. It will reform if removed by scratching or machining. The addition of nickel to the structure (8 wt.% Ni minimum in the commonly used 304 type stainless steel and 10 wt.% Ni minimum in the more corrosion-resistant 316) broadens the range of passivity established by the chromium. Further, addition of molybdenum (2 wt.% minimum in 316) further expands the passivity range and improves corrosion resistance (see table).

TABLE 1. ALLOYING ELEMENTS AFFECT STAINLESS-STEEL CORROSION PROPERTIES

ELEMENT	EFFECT ON STAINLESS STEEL
Chromium	Forms a passive film with oxygen that prevents further diffusion of oxygen into the surface of the steel
Nickel	Increases ductility and toughness; increases corrosion resistance to acids; Ni addition creates non-magnetic structure
Molybdenum	Increases pitting and crevice corrosin resistance; increases resistance to chlorides
Copper	Increases corrosion resistance to sulfuric acid
Manganese	Acts as a substitute for nickel in 200-series stainless steel
Titianium/Niobium	Ties up carbon and prevents inter-granular corrosion in welded zone of ferritic grades
Nitrogen	Increases strength and corrosion resistance in austenitic and duplex grades
Silicon	Improves resistance to high-temperature scaling
Sulfur	Usually kept low except for "free-machining" grades
Carbon	Usually kept low; used in martensitic grades to increase strength and hardness

Source: "Alloying Elements in Stainless Steel" by Pierre-Jean Cunat, Published by the Internation Chromium Development Association

Corrosion mechanisms

Stainless steel resists general corrosion well, but several mechanisms can result in localized corrosion of stainless steel. For example, pitting occurs in areas where the stainless steel's protective passive layer breaks down on an exposed surface. Once initiated, the growth rate of the pit can be relatively rapid and can result in localized, deep cavities.

Crevice corrosion occurs in locations where oxygen cannot freely circulate, such as tight joints, under fastener heads and in other areas where pieces of metal are in close contact.

Pitting and crevice corrosion of stainless steels generally occurs in the presence of halide ions (chloride is most common). Moisture from the environment, along with chloride salts and pollutants, accumulates in the crevices, creating an acidic environment inside the crevice where oxygen is depleted and chloride concentration is elevated. This environment promotes the breakdown of the passive film and anodic dissolution.

The main environmental factors that favor localized attack include higher chloride concentration, elevated temperature, lower pH and more cathodic corrosion potentials.

Specific corrosive environments, such as the presence of chlorides, combined with tensile stress, can crack stainless steels in a mode of attack known as stress corrosion cracking (SCC).

Another corrosion mechanism involves the metal's microscopic grain structure. Rapid corrosive attack of immediately adjacent grain boundaries with little or no attack of the grains is called intergranular corrosion.

Corrosion resistance

Corrosion of carbon steel can be minimized with protective paints and coatings, or by cathodic protection, such as galvanizing (applying a zinc coating to interfere with the natural electrochemical reactions in corrosion). Modifying the operating environment with corrosion inhibitors can also be effective in some cases. The resistance of a stainless steel to localized attack is strongly related to its alloy content.

Chemical passivation refers to the chemical treatment of stainless steel with a mild oxidant, such as nitric acid or citric acid solution, for the purpose of enhancing the spontaneous formation of the protective passive chromium oxide film. ■

For more on corrosion, see *Chem. Eng.*, March 2014, pp. 40–43 and July 2012, pp. 26–29.

Relevant links

1. Specialty Steel Industry of North America. www.ssina.com/overview/alloyelements_intro.html
2. ASTM International. Standard A380. www.astm.org/Standards/A380/
3. Steelconstruction.info
4. Corrosionist. www.corrosionist.com/Pitting_Crevice_Corrosion.htm

Propane Dehydrogenation: Oxydehydrogenation

By Intratec Solutions

Propylene is a major component of the global olefins market and is widely used as an intermediate for an array of chemical and plastic products.

Propylene is produced as a byproduct in steam crackers and through fluid catalytic cracking (FCC) processes. However, due to the increased availability of inexpensive ethane from shale gas, ethane has been preferentially used as a feedstock in steam crackers over naphtha, a practice that results in minor propylene production.

In this context, on-purpose propylene production routes are of great interest to the petrochemical marketplace. Among them, propane dehydrogenation (PDH) technology is an attractive option, and has been applied in several plants around the world.

The process

The PDH process depicted in Figure 1 is similar to the STAR (steam active reforming) process (Uhde GmbH; Dortmand, Germany; now ThyssenKrupp Industrial Solutions; www.thyssenkrupp.com), which applies the oxydehydrogenation principle. Two other PDH processes were previously discussed in this column (*Chem. Eng*., Feb. 2013, p. 33 and Jan. 2014, p. 27).

The STAR process was the first to apply the oxydehydrogenation principle for propylene production, significantly enhancing performance. In this technology, O_2 is added to the system to react with H_2, forming water. This reaction lowers H_2 partial pressure, shifting the equilibrium to higher conversion of propane into propylene while providing the required heat of reaction. Figure 2 shows the effect of O_2 addition on propane conversion, according to different O_2-to-propane molar ratios.

Reaction. Propane is fed into a depropanizer column for heavy impurities removal. The depropanizer distillate is vaporized, mixed with steam, and preheated before entering the reformer reactor, which is an externally fired tubular reactor where most of the propane conversion occurs. Next, the reformer effluent is fed to the oxyreactor, where H_2 is selectively combusted by O_2. The process gas is cooled in a series of heat exchangers to recover process heat. Then, it is compressed and sent to the next area.

CO_2 separation. The compressed gas is fed to an absorption column, where CO_2 is removed in the bottoms by washing with an aqueous piperazine-activated methyldiethanolamine (MDEA) solution. The bottoms stream is depressurized, liberating gases that are recycled to the absorption column. The CO_2-rich liquid solution from the flash vessel is fed to the solvent regeneration column, which separates CO_2 in the overheads from the MDEA solution in the bottoms, which is recycled to the absorption column.

Gas separation. The overhead stream of the absorption column is dried in a molecular sieve and fed to a low-temperature separation system (cold box) for the removal of lights. In this system, a H_2-rich stream is also obtained, and is purified in a pressure swing adsorber (PSA) unit to obtain high-purity H_2 byproduct.

Fractionation. The liquid fraction from the cold box is sent to the fractionation area, which consists of a deethanizer column for removal of lights and a propane-propylene (P-P) splitter, where polymer-grade (PG) propylene is obtained. Unreacted propane from the splitter bottoms is recycled.

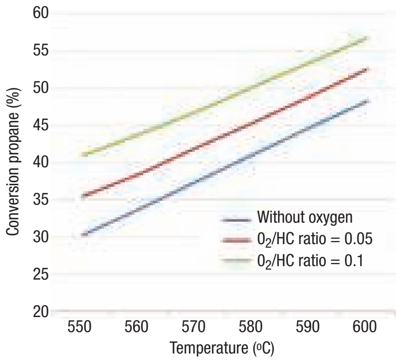


FIGURE 2. O_2 impact on propane conversion

Economic performance

An economic evaluation of a PDH plant was conducted, assuming a facility with a nominal capacity of 450,000 ton/yr of PG propylene erected at a petrochemical complex on the U.S. Gulf Coast (no storage for feedstock and product was considered).

Estimated capital expenses (total fixed investment, working capital and initial expenses) for such a plant are $400 million and estimated operating expenses are $770/ton of product.■

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

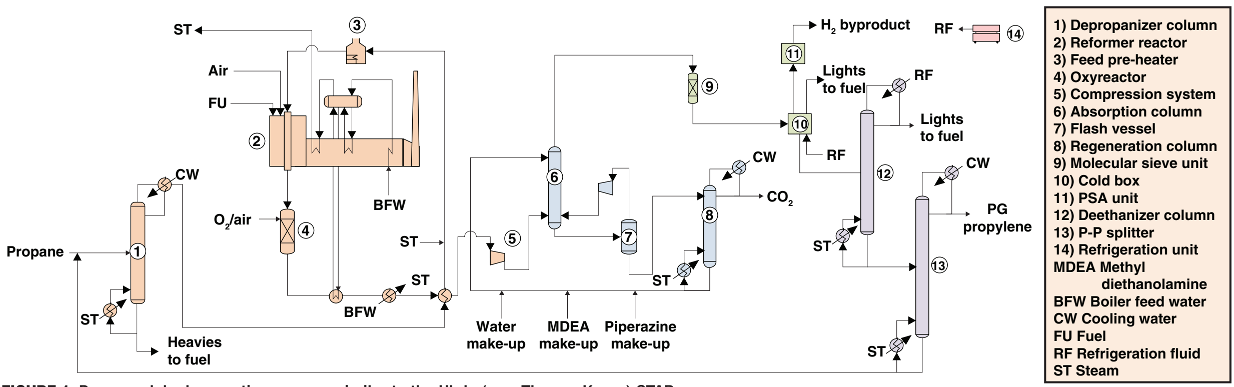


FIGURE 1. Propane dehydrogenation process similar to the Uhde (now ThyssenKrupp) STAR process

Why Bad Things Happen to Good Steam Equipment

Part 1

Accounting for an entire steam-trap population is crucial to avoiding safety incidents and sub-optimal production — high-priority consideration must be given to steam-system management

James R. Risko
TLV Corp.

IN BRIEF

WHAT CAN GO WRONG IN A STEAM SYSTEM?

ANALYZING A STEAM-TRAP POPULATION

MANAGEMENT PRIORITIZATION

EVALUATING THE NUMBERS

SYSTEM GOALS

CREATING A NEW PARADIGM

Historically, steam systems have provided the most effective source of readily conveyable heat to industrial process applications, including those in the chemical process industries (CPI), and there is no similar low-cost substitute that can replace steam. Without steam, industrial production would be dramatically curtailed, and the low-cost manufactured products that are made from steam's heat or power-generation assistance would not exist. Without steam, our quality of life, economies and society in general would suffer.

While many CPI workers may appreciate that steam systems are a necessity, the same individuals may have also experienced negative steam-related incidents throughout their careers, making them harbor unfavorable thoughts. Specifically, these events may have resulted in safety issues, equipment failures and unscheduled shutdowns of a unit or a full production line. Safety events are extremely challenging and sorrowful issues if someone is injured, and shutdowns can be disruptive to the entire workforce. It is not surprising, then, that people lack an enthusiastic attitude when it comes to steam.

FIGURE 1. Effective steam traps keep heat in the system to optimize production rates and heat quality, and they also discharge condensate to provide for system safety and reliability. Major problems can occur if condensate is not readily drained from the system

What can go wrong in a steam system?

What types of issues can arise in a steam system, and can listing and classifying these items help to determine an executable prevention path or risk-mitigation procedure? Of course, it is relatively easy to identify the most common maladies seen in a steam system. There can be waterhammer, erosion damage and steam leaks in utility systems or equipment. Such destruction may render critical process equipment, such as turbines, flares or heat exchangers, unusable. Additionally, high return-system backpressure caused by steam leakage or blowthrough from bypass steam might restrict production quantity or quality through heat-exchange equipment. Backpressure can also cause the heat-exchange application to be put on bypass or to waste condensate by routing to ground level. While some steam-system failures are common, the challenge then is to identify the

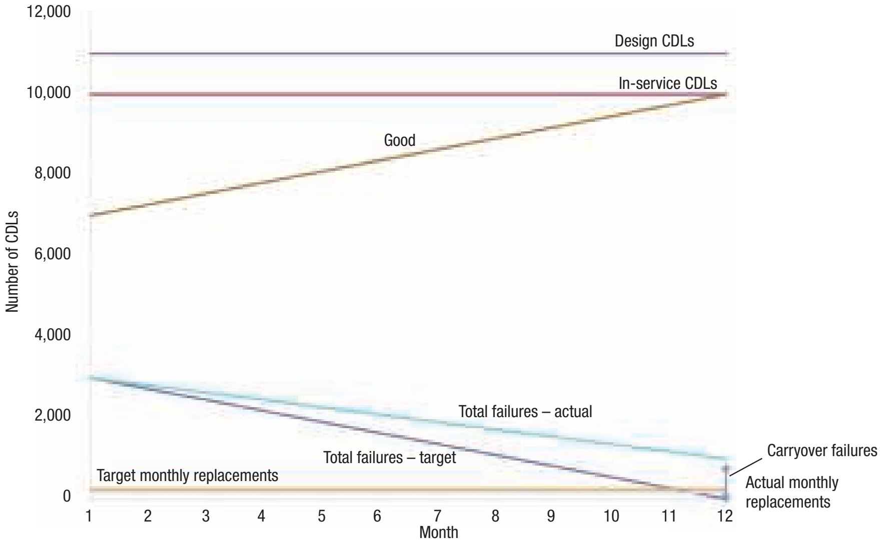


FIGURE 2. A typical steam plant has less in-service condensate discharge locations (CDLs) than the original design. As total failures are reduced through monthly replacements, the number of "good" CDLs increases. If actual replacements are less than known total failures, carryover failures result, thereby reducing available good CDLs to effectively drain the system in the subsequent year. For more details, see the calculation box on p. 26

sources of these incidents. This leads to the larger question, "Why do bad things happen to good steam equipment?"

The technical answer lies in understanding that the cause for a large percentage of failures might be due to the steam system not being maintained to the "as-built" or "design" specification. The original designers analyzed the plant requirements and determined the most suitable design, according to their expertise and standards. That original design included the correct number of steam traps and the assemblage of piping and components that help to drain condensate from the system. Commonly referred to as a condensate discharge location (CDL), the total assembly is required to remove condensate and effectively maintain the design performance of the steam system. Once built, the plant is handed over to the end user for operation and maintenance — with the expectation of sustaining the initial design. Unfortunately, that is when operational budgets, personnel turnover and, in some cases, inexperience with steam systems may play a causal role in negative events.

Analyzing a steam-trap population

Steam traps (Figure 1) are ubiquitous in steam systems, and when operating effectively, they can efficiently retain heat in the system. Consider the analysis of a hypothetical plant's steam-trap population shown in Figure 2. Based on this plant's "state of the population" summary, it is seen that the original design (and as-built) condition included 11,000 CDLs. Over time, the plant's management decided to decommission and remove 1,000 steam traps from service, leaving only 10,000 in-service CDLs. In this example, no plant personnel could find documentation to support why 1,000 steam traps were decommissioned, because no part of the plant had been shut down.

When the in-service quantity of CDLs is lower than the design calls for, then it may be that the reduction was due to a misunderstanding of the importance in maintaining the design total, or possibly from general neglect of the trap population. If the discrepancy is not explainable, then the system's drainage is restricted from the originally required capability. Here, the target for total in-service CDLs should be increased to equal the original design total of 11,000 CDLs.

When routinely administered, steam-trap surveys conducted by plant personnel (Figure 3) provide invaluable information for evaluating the health of the steam system. As it turns out, in this hypothetical example, several years had passed since the last trap survey was completed. So, when the current survey was finished, it was found that there were 3,000 trap failures (both hot leaking failures and cold-blocked low-temperature failures occurred); and 7,000 traps were considered to be in good condition. This sit-

FIGURE 3. Accurate and regularly sustained diagnosis of steam traps' operating conditions is essential to determining the population's current health (state of the population). Once failures are identified, the information is valuable for allocating resources to restore all condensate discharge locations to an "as designed" operating condition for safety and reliable performance

CALCULATION EXAMPLES

Estimating annual new failures

(Reported failures – Carryover failures) / Years between surveys

Example: (3,000 reported failures – 1,000 carryover failures) / 2 years = 1,000 annual new failures

Average trap life

(Total in-service population) / (Annual new failures)

Example: 10,000 traps / 1,000 traps failed in a year = 10 year trap life expectancy

Annual Failure Rate

(Annual new failures) / (Total in-service population)

Example: 1,000 traps / 10,000 traps = 10% annual failure rate

State of the Population

(Failures) / (Total in-service population)
(Good traps) / (Total in-service population)

Example: 3,000 failures / 10,000 traps = 30% state of failure
7,000 good traps / 10,000 traps = 70% good state

uation creates a significant operational and maintenance dilemma for the site.

If the goal is to have a "zero reset" scenario, in which all failed traps must be repaired, and the cost to repair the average failure is \$600, then \$1.8 million is needed from the year's budget to accomplish the target. To achieve this goal, 250 steam traps must be replaced each month, which represents two or three maintenance crews working full time for a year, assuming that every trap is accessible and can be isolated for repair or replacement. It is certainly a monumental task that may have been caused by an improper course of action a number of years before, when trap replacements were not completed in sufficient quantity to keep pace with the annual failure rate (amount of failures per year) of the population.

Consider that the average annual failure rate of a steam trap population in a mature plant can be estimated from historical records, provided that there are at least two survey events within a period of 4–5 years. Simply subtract the carryover failures (failed traps recorded from a prior survey for which no action was taken to repair) from the reported failures that were recorded in the survey. The remainder is the quantity of new failures. The number of new failures can be divided by the number of years since the prior survey to provide an estimate of the average annual new failures of a steam trap population. Several related useful calculations are shown in the box above.

In this hypothetical plant history, if the management of the trap population had been continuous and sustainable at an annual failure rate of 1,000 (10%), then the plant should only have to support the repair of 84 traps per month, not 250 traps. However, in this case, the trap population was allowed to deteriorate to 3,000 failures (30% failure state), and this situation places a tremendous burden on resources. Worse still, if not corrected, the failures can be expected to grow until catastrophic events occur.

One takeaway from this example is that for every 1,000 traps that must be repaired in a year, there is a requirement for the planning and repair resources to correct 84 traps monthly without fail. That replacement requirement equates to repairing 4–5 CDLs per day, with any lesser amount creating a gap at year-end; the difference here equaling the next year's carryover failures.

Steam traps must be replenished or repaired in order to maintain a sustainable operation. Not taking the highest-priority corrective action with regard to steam trap failures is somewhat comparable to reusing a teabag even though it no longer dispenses flavor — although there is a teabag in service, it no longer provides a useful purpose. Similarly, if a steam trap has failed — particularly via a cold failure — then the CDL is no longer serving its intended purpose, and must be repaired.

Is there any question about what outcome should be expected if all of the steam traps and related CDLs in a system were simply isolated by valving, thereby completely removing their drainage capability? There would be no way to automatically remove condensate from the system, creating a highly dangerous situation. What about if just 30% were shut off, or 50%? It is akin to gambling with the safety of the plant, as the potential formation of condensate slugs in the pipeline can lead to unstable, hazardous conditions. It is extremely distressing to consider a site that is not replacing trap failures due to a budget constraint, because the timely repair of traps allows the system to operate at the intended conditions. This must be seen as an inflexible demand. Timely action should be mandatory, not optional, to optimize the operation of a steam system.

Management prioritization

In a properly drained and maintained steam system, it is critical that the steam flowing

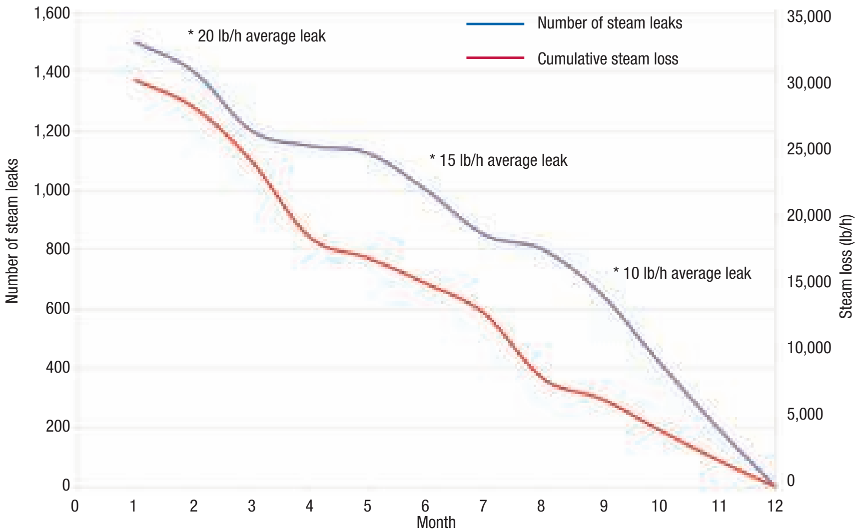


FIGURE 4. Often, high priority is given to fixing the leakage failures or hot failures to reduce steam loss and increase profit. Commonly, the repair of hot failures with high-value loss is given first priority in instances other than very critical applications. A representative example of the correlation of yearly repairs to reduction in steam loss is shown here

within the system remains at near-saturated quality and that avoidable backpressure in the return header is reduced, in order to diminish the likelihood of waterhammer, erosion, corrosion and plating. Superheated steam or steam with near-saturation quality normally cannot cause hammer or high erosion at normal velocities because there is not enough condensate to be propelled downstream. Hammer and erosion occur when liquid pools in the system are thrust at high speeds, but when a system is properly drained, the damaging component is missing. Once again, it is evident that steam-trap failure rates are reduced in successfully maintained steam systems, enabling efficient condensate removal from the system.

Maintaining CDLs to manufacturer specifications helps to eliminate steam leakage (hot failures) and blocked discharge conditions (cold failures). When CDL failures — both hot and cold — are minimized, insulation is maintained and boilers are not pushed beyond their specified limits, the steam system can be optimized with regards to condensate drainage, as well as the ability to sustain steam quality when transported throughout the system.

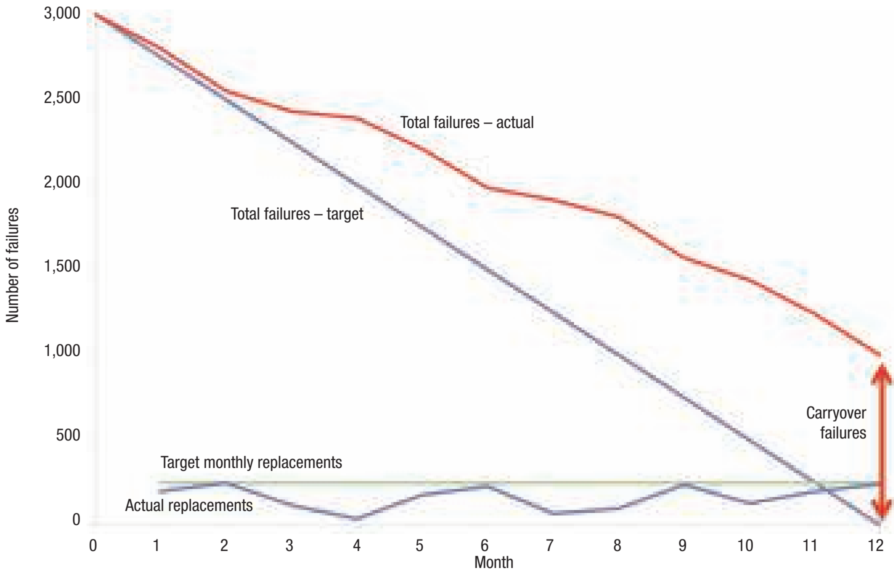
It sounds simple enough — maintain the insulation, keep the boiler within its limits and ensure that the steam trap population provides for quality condensate drainage. It certainly sounds straightforward in concept. If it were so readily attainable, then why isn't this goal accomplished more often?

Evaluating the numbers

In many plants, the typical program to manage the steam trap population may be controlled by budget constraints, by changing responsibilities or by a lack of priority. Although plant operations can be critically affected, the budget may be controlled by maintenance that requires close collaboration and coordination between departments. However, regardless of the circumstance or cause, it sometimes seems that once a system has reached a manageable level after years of cooperation and dedication, then the operational problems are minimized and some portion of the trap maintenance budget is reassigned to a different project not related to trap repair. Then, the portion of the trap population considered to be "good" suffers by seeing an increase in carryover failures, and often no survey action takes place for an extended time. All the while, new failures are accumulating, thereby reducing the safety, reliability and performance of the system. This situation is unfortunate, because the system had finally reached a relatively sustainable condition. Subsequently, after several years of inaction, the plant's trap population may deteriorate so much that a significant negative incident occurs. At this point, the follow-up (some might say knee-jerk) reaction may be to fix the steam system very hastily. This is an all-too-frequent scenario that can lead to the previously presented example where 3,000 traps failed at a single site.

Once failures have been identified, then the focus is often placed on fixing

FIGURE 5. For zero reset of all 3,000 failures, monthly replacement of 250 CDLs is required. If actual replacemnents monthly are reduced, the gap results in year-end carryover failures that reduce the effective good in-service CDLs in the next year



the hot failures, because these repairs can be readily justified by simple energy-cost analysis. Figure 4 illustrates a typical close relationship between hot-failure traps and reduced steam loss. Especially in times of very high energy prices, incredible emphasis is placed on reducing the cost of operations by fixing leaking steam traps. A progress chart, similar to the one shown in Figure 4, can be generated and tracked. Thus, if the project plan is to eliminate 3,000 failures from the hypothetical plant, then the corresponding requirement is to repair 250 CDLs per month, otherwise there will be a carryover failures gap (see Figure 5 for additional analysis).

The carryover failures represent the real world; rarely do plants correct all or even nearly all of the failures. The result is that a significant number of CDLs are not restored to proper drainage operation, and it is not uncommon to carry a sizable number of failures over to the following year. Once carryover failures are accepted in a plant's operations, the steam system becomes destined for sub-optimal and potentially unreliable operation.

What follows when 1,000 carryover failures are extended into the following year? Instead of correcting all 3,000 failed steam traps (a zero reset mentality), suppose that the plant management allocated a budget for repair of only 2,000 failures instead. Perhaps this thought process stems from the expectation that with 2,000 failures corrected, the next annual period will only require budget for 1,000 failures. However, that is not an accurate scenario, because those 1,000 CDLs represent carryover failures only, and the plant also must consider new failures. In a plant with an average steam-trap lifecycle of ten years, the actual failures could be estimated as 2,000, consisting of the 1,000 carryover failures just identified and 1,000 new failures. While the diagnosis of each trap in the population is performed at regular intervals (usually annually or semi-annually), new failures are constantly occurring, as illustrated in Figure 6.

If carryover failures are included as part of the repair strategy, a significant number of CDLs will be operating improperly, thereby increasing the chances of a debilitating incident occurring within the plant. For this reason, it is not recommended to adopt a work process that allows carryover failures and focuses only on those traps that have already been fixed. Instead, a paradigm shift is required.

System goals

Applying maintenance action to individual steam traps is a path action, but not an overarching system goal. Risk lies in the false sense of security that is given when the goal is simply to repair a given number of steam traps, and the real goal of achieving an optimized steam system is neglected. So, if the annual target is established to fix 2,000 steam traps and only 1,000 traps are repaired, there might be some explanation of mitigating events that explains the lapse. In such a situation, the carryover failures might be considered acceptable under the circumstances, and a new goal is assigned for the next year. However, this is a dangerous situation, because while the potential for damage is not visible, it is prevalent in the unaddressed sections of the steam system, and

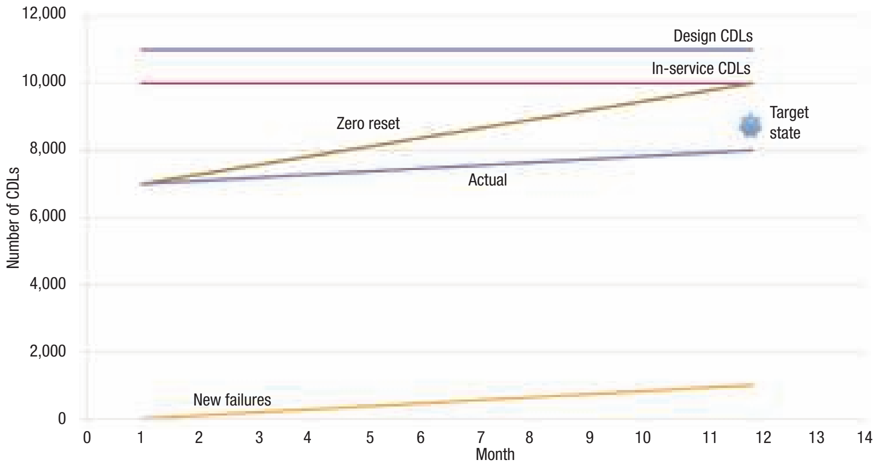


FIGURE 6. There is always an identification-repair response-time lag between diagnosis and maintenance action. Although a site may elect to perform sufficient repairs to reach a target state of the CDL population at year-end, new failures occuring during the repair period always lower the actual year-end state. It is just one of many justifications for adopting a zero reset mentality for maintenance-response planning

the downstream recipients of that steam. The potential for peril can increase in severity over time.

Without a full understanding of the long-term impact on a steam system, there can exist a false impression that a system can be well managed, even if there is allowance for carryover failures. Figure 7 provides additional insight into a longer-term view. As it turns out, the best possible theoretical state of the population occurs only after a zero reset condition is experienced from the prior survey report, and when accumulated repairs equal new accumulated failures. After the midway point, zero reset has been theoretically reached, and new replacements cease, as there are no known failures that remain to be repaired. However, unidentified new failures are still occurring and will not be recognized until the next survey.

The result is that the best state deteriorates between the prior and new surveys, with the theoretical "best sustainable" condition being realized at the beginning date of the next survey. This theoretical point occurs midway between the prior survey and the next survey date — if annual surveys are conducted, and repair is immediate and linear, then the best good state occurs at midyear.

If the original goal of the designers is recalled, it was to have 11,000 fully functional CDLs at the site. For whatever reasons, the plant's management decided to decommission and remove 1,000 installations, leaving a population of only 10,000 in-service CDLs (a 9% reduction from the design). Even if there is perfect harmony

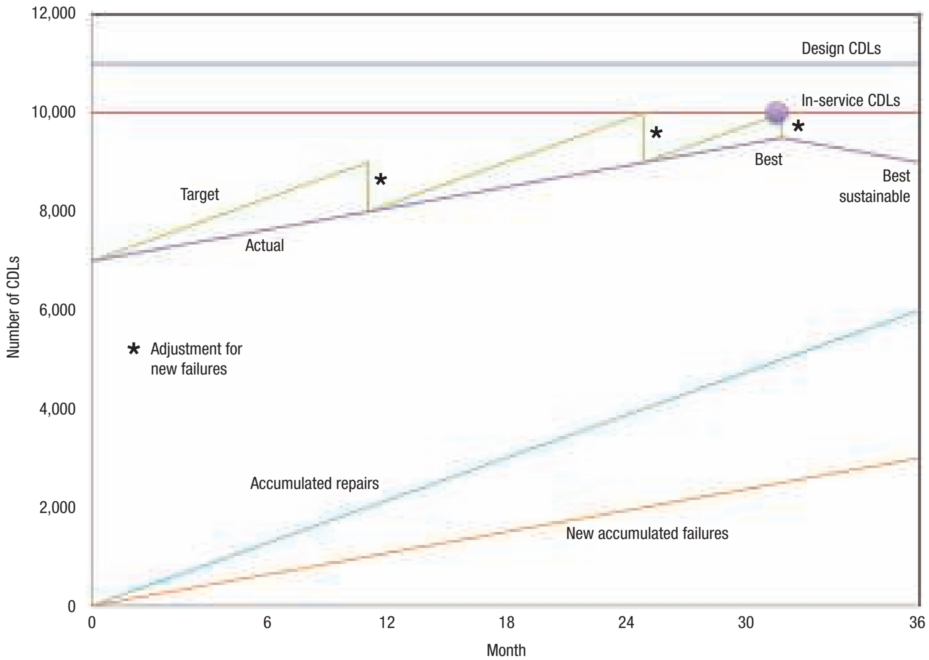
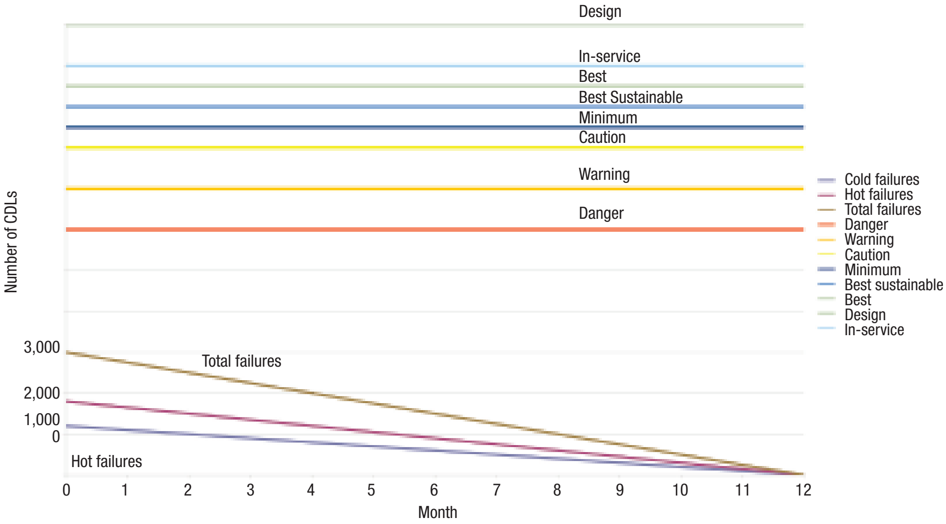


FIGURE 7. Sites sometimes decide upon a fixed number of annual repairs instead of striving for zero reset, thinking they can achieve a nearly 100% good in-service CDL population state over several years. However, due to new failures during the repair cycle, the theoretical "best sustainable" condition is reached midway through a perfectly correlated, linear inspection and repair term, after which the number of CDLs in good condition will decline

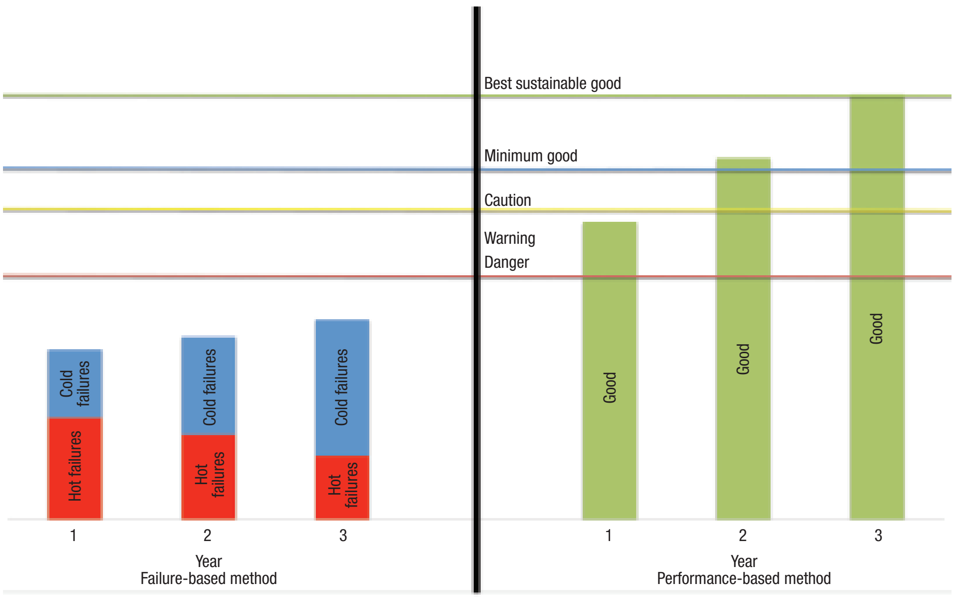
FIGURE 8. The number of in-service CDLs is already a reduction from the number of CDLs in the original design, which is not desirable unless clearly justified; and even with a zero reset focus and perfectly harmonized inspection and repair, the "best sustainable" condition is controlled by the number of annual failures. Establishing critical threshold values provides clear direction for sustainable steam-system performance



with replacement equipment to achieve a "best sustainable" state, that already represents an 18% drop in drainage capability from the design. At this point, it is also important to consider how much redundancy the professional engineering firm included in the original design. Understanding the effect of reducing the number of in-service good CDLs from the design, it can be seen that a key step is to increase the quantity of in-service CDLs until it reaches the design total, less any trap stations clearly suitable for decommissioning.

Furthermore, once carryover failures and new failures are considered, it is possible to have only 7,000 or 8,000 correctly functioning CDLs; which in the case of the former, represents just 63% of the original design. Starting the next year with only 63% of the original design total considered to be in good condition is dangerous, especially if there is an additional lapse in repair action. It can be expected that another 1,000 traps would fail without any repair of previously failed traps. In such an instance, the portion of the population functioning correctly for system drainage could be reduced to 6,000 traps — only 54% of the original design.

FIGURE 9. A paradigm shift directs full attention to the performance-based method, rather than focusing mainly on hot failures. Knowing the number of "good" CDLs relative to key threshold levels provides a clear indication of the steam system's health and performance expectations



Creating a new paradigm

This is where the necessity of a paradigm shift comes to the forefront. The goal is not to repair failed traps, but rather to maintain a minimum threshold of CDLs in functional condition. That quantity of good CDLs should always refer to the original design total, not to the quantity that are currently in service. Instead of the focus on hot failures, steam loss or accumulated repairs, a site should shift attention to sustaining an acceptable "good" threshold value for the state of the population — with specific, strict dates to start the survey every period. The established survey start date becomes sacrosanct and is held steadfast, regardless of daily interferences. The survey takes such a high priority simply because a steam system is indispensable to the production success of a safely operating plant. It should not be a second- or third-priority focus, but the key focus, thus helping to ensure an optimized steam system.

Another important factor that must be addressed is outsourcing, which is the allocation of responsibilities to third-party entities as contractors to perform certain work. In order to achieve a sustainable program under an outsourcing scenario, there are several crucial requirements: certified test personnel; validated equipment for making accurate condition judgments; and standardized application drawings for correct installation of repaired equipment. In some plants, testing and maintenance may be conducted by the same third-party entity. Regardless, whether a singular third-party or multiple entities are involved with activities that can affect the state of the population, it is important that the capability for each process is confirmed. For example, an incredibly capable contractor for piping repair may be insufficiently trained for testing activities, and must be suitably educated and certified for these tasks. Most critically, there should exist a regular audit process to check and confirm the accuracy of the surveyors' qualification certificates, the actual judgments performed by those surveyors, and in the case of maintenance contractors, the correct installation of each repaired CDL. In some instances at least, the engagement and dedication to a steam system by owner personnel can be higher than with contractors, so a regular and ongoing audit process is recommended to help obtain sustained high-quality work on such critical responsibilities.

With consideration for the site employees who manage the steam system — because responsibilities and personnel change — guidelines must be established. In order to implement clear ongoing parameters for safe and reliable operation, a plant should determine required threshold target and notification values that can be used as the primary focus for the team responsible for maintaining system performance. Figure 8 shows the different key threshold levels of "good" CDLs as: "minimum," "caution," "warning" and "danger." Note that "best sustainable" is a theoretical condition for which it is possible to approach this level, and "minimum" is the determined threshold below which safe and reliable operation of the steam system can be adversely affected. Other tiers provide information to operations and maintenance personnel on the reasonable expectations of increased risk, should appropriate action not be executed.

If a plant wants to have a secondary focus on cold failures to reduce problems caused by condensate in the system, or to repair hot failures to reduce backpressure and recover profits lost to unnecessary energy production, that is certainly a fine approach to fixing failed CDLs. However, when the big picture is to achieve safe and reliable plant operations, the primary focus, as shown in Figure 9, must be to measure the number of good CDLs that are draining the system. Plants should establish the target of keeping the good CDLs between the "minimum good" and "best sustainable good" state threshold values.

When the goal is to maintain a state of the population at or above "minimum good" levels for safety and reliability considerations, the target is straightforward. Now, the repair of failures becomes just a path, not a goal. With a clear message to personnel, the steam-system drainage can be optimized and sustained for best plant performance. ■

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For suggested additional reading on steam systems, see the online version of this article at www.chemengonline.com.

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Part 2

Mitigate Corrosion in Condensate-Return Systems

Understanding the chemistry behind corrosion in condensate-return systems can aid in selecting and properly employing the best mitigation technique

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IN BRIEF

CORROSION MECHANISMS

COMBATTING CORROSION

CONTROLLING CORROSION

MONITORING CORROSION

The importance of steam-condensate return systems to boilers in the chemical process industries (CPI) cannot be overemphasized, especially with regard to enhancing operating efficiency. This also enables water conservation by reducing waste. However, condensate-return systems are prone to severe corrosion due to the presence of non-condensable gases, like carbon dioxide (CO_2) and oxygen (O_2), which are associated with steam generation. This often renders a condensate-return system ineffective, and can result in additional energy costs, as well as the extra cost of replacing lost boiler feedwater. Table 1 provides an example of the costly effects of corrosion (in this case, two 2-mm holes that developed in a condensate line due to corrosion that caused water loss). The cost impact of lost condensate and makeup water can be substantial if several leaks develop in the entire condensate-return system. This article provides an overview of some current technologies used to combat the underlying corrosion issues in condensate-return systems, and the ways to deploy these corrosion-mitigation techniques effectively.

Corrosion mechanisms

As a first step to combat condensate-system corrosion, the ingress of gases into the condensate system should be minimized. Ingress of gases can occur in the following ways:

- Non-condensable gases (CO_2 or O_2) absorbed from the air can dissolve in boiler makeup water; in this case, the non-condensable gas flashes over the steam and eventually finds its way into the condensate
- Absorption of non-condensable gases in equipment that is initially full of air (steaming operation during startup) or air leakage in equipment that is handling steam at sub-atmospheric pressures
- CO_2 produced in the boiler by the decomposition of boiler-feedwater alkalinity that has dissolved into the condensate

TABLE 1. EFFECTS OF CORROSION ON FUEL-OIL COSTS AND MAKEUP WATER USAGE

Condensate header pressure, barg	5
Condensate temperature, °C	159
Makeup water temperature, °C	30
Boiler efficiency, %	80
Fuel-oil cost, $/million kJ	24.2
Additional fuel-oil cost, $/yr	97,300
Additional makeup water, metric tons (m.t.)/yr	5,900

The following section outlines some specific chemical-reaction mechanisms that can cause corrosion in steam-condensate return systems.

Condensate system corrosion in the presence of oxygen. The following reaction represents the corrosion of iron (Fe) in water [*1*]:

$$Fe + 2H_2O \leftrightarrows Fe(OH)_2 + H_2$$

This reaction continues to equilibrium if no O_2 is present [*2*]. Also, the formation of ferrous hydroxide ($Fe(OH)_2$) increases the condensate pH and retards the reaction rate. When O_2 is present in the condensate, the following reaction occurs, forming hydrated ferric oxide ($Fe_2O_3{\cdot}H_2O$):

$$4Fe(OH)_2 + O_2 \leftrightarrows 2Fe_2O_3{\cdot}H_2O + 2H_2O$$

TLV

FIGURE 1. In the presence of oxygen, ferric-oxide corrosion occurs, and can wreak havoc on condensate-system equipment

Ferric oxide, also called hematite or red rust, is a loosely adhering oxide layer, and can travel with the condensate flow through the condensate piping. An example of iron-oxide corrosion is shown in Figure 1. The ingress of dissolved O_2 in the condensate prevents equilibrium from being reached, and ferrous hydroxide is removed continuously from the inner walls of the piping and fittings [*2*].

The following are the two types of corrosion that occur when O_2 is present [*3*]:

- Generalized corrosion on the metal surface, which causes a loss of metal from the entire surface
- Oxygen pitting, which causes a highly localized loss of metal that can result in a catastrophic failure in a short time. Pitting begins at weak points in the oxide film and at locations where the film is damaged. The corrosion penetrates into the surface, effectively drilling a hole into the metal

Condensate system corrosion in the presence of CO_2. Carbonates and bicarbonates, such as sodium bicarbonate ($NaHCO_3$) or sodium carbonate (Na_2CO_3), are commonly present in boiler makeup water, and these anions are generally called "water alkalinity." With the application of heat, these carbonates undergo the following reactions in the boiler [*1*, *3*]:

$$2NaHCO_3 + heat \leftrightarrows Na_2CO_3 + CO_2 + H_2O$$

$$Na_2CO_3 + H_2O + heat \leftrightarrows 2NaOH + CO_2$$

As the steam from the boiler transfers its latent heat and condenses, the CO_2 dissolves in the condensate, depressing the pH. The following reversible reactions take place:

$$H_2O + CO_2 \leftrightarrows H_2CO_3$$

$$H_2CO_3 \leftrightarrows H^+ + HCO_3^-$$

$$HCO_3^- \leftrightarrows H^+ + CO_3^{2-}$$

The corrosion of iron by carbonic acid (H_2CO_3) is promoted by hydrogen ions (H^+) from the above dissociation reactions. The overall reaction forming ferrous bicarbonate ($Fe(HCO_3)_2$) is:

$$2H^+ + 2HCO_3^- + Fe \leftrightarrows Fe(HCO_3)_2 + H_2$$

A low pH causes generalized loss of metal, rather than the localized pitting caused by O_2. Corrosion is characterized by the general thinning of the pipe wall or grooving along the bottom of the pipe [*2*]. This thinning often leads to failures, particularly at threaded joints. In addition, corrosion that causes decay of pipe walls leads to debris that can deposit in small parts, causing blockage, as seen in Figure 2.

Combatting corrosion

As stated previously, the ingress of O_2 or CO_2 into the condensate is the main cause of corrosion in condensate systems. Hence, any effort to reduce corrosion to acceptable levels must deal with expelling these gases from boiler water and neutralizing their corrosive effect with the addition of chemicals [*1*,*3*]. The main processes for fighting condensate-system corrosion are summarized in the following sections.

Deaeration. The boiler feedwater is mainly comprised of makeup water and return condensate. Dissolved O_2 is primarily present in boiler makeup water, while dissolved CO_2 can be present in the return condensate. Both gases introduce corrosion potential for the boiler and the condensate system. Deaeration effectively reduces dissolved non-condensable gases from feedwater. In the deaeration process, the makeup water and return condensate are heated in a deaerator vessel with low-pressure steam to a temperature that is sufficient to reduce the partial pressure of the dissolved gases over the water surface. This results in almost all of the dissolved gases coming out of the liquid phase. The dissolved gases are vented from the deaerator vessel along with a small amount of low-pressure steam to aid venting. This process is known as mechanical deaeration.

Chemical oxygen scavenging. Some residual O_2 remains after mechanical deaeration, as the partial pressure of O_2 cannot be reduced to zero. This is a potential source for O_2 corrosion. Chemicals are added to react with the leftover O_2. The chemical is usually added below the water level in the water-storage section of the deaerator. The most common O_2 scavenger is catalyzed sodium sulfite ($2NaSO_3$), which has the following reaction:

$$2NaSO_3 + O_2 \leftrightarrows 2NaSO_4$$

Another O_2 scavenger is diethylhydroxylamine (DEHA; $4(C_2H_5)_2NOH$). The overall reaction of O_2 with DEHA is as follows:

TLV

FIGURE 2. Corrosion in pipe walls can lead to widespread issues, including the formation of deposits and blockages in small piping components

$$4(C_2H_5)_2NOH + 9O_2 \leftrightarrows 8CH_3COOH + 2N_2 + 6H_2O$$

The addition of DEHA also has a passivating action on metal surfaces. When hydroxide alkalinity is present in the boiler water, the acetic acid is neutralized and removed in blowdown as sodium acetate.

Controlling corrosion

The objective of chemical control in the condensate is to elevate the condensate's pH so that the ingress of carbonic acid is neutralized. Neutralizing amines ($R–NH_2$) are used to neutralize the acidic H^+ that is generated by the dissociation of carbonic acid. Neutralizing amines also serve to increase the pH of the condensate. The amines hydrolyze when added to water, and generate the hydroxide ions that are necessary for neutralization. The chemical reaction for a neutralizing amine in water is as follows:

$$R–NH_2 + H_2O \leftrightarrows R–NH_3^+ + OH^-$$

The overall neutralization reaction is shown below:

$$R–NH_3^- + OH^- + H_2CO_3 \leftrightarrows R–NH_3^+ + HCO_3^- + H_2O$$

By regulating the dosing rate of the neutralizing amine, the pH of the condensate can be elevated to the desired level. Many amines are used for condensate-acid neutralization and pH elevation. Morpholine and cyclohexylamine are common neutralizing amines. Often, a blend of morpholine and cyclohexylamine is a better choice than using either alone. The choice of neutralizing amine depends upon the distribution ratio and the number of condensation sites [3].

Another option for controlling condensate-system corrosion is the use of filming amines. Octadecylamine is a common filming amine. Filming amines are introduced into the steam header, and form a very thin amine-film barrier on the metal surface by replacing the loose oxide scale. This barrier layer prevents O_2 and carbonic acid from reaching the base metal in the condensate-return lines. During the initial dosing period, loosely adhered oxide deposits are lifted off of the metal surface and replaced by an amine film. This is due to the surfactant properties of the amine.

In the case of old or untreated condensate lines, excessive dosage of filming amines can dislodge pre-existing deposits and the sludge can foul the condensate-return system. This sludge can potentially reach the boiler, causing tube failures. However, for uniform and effective coverage of a large condensate-return system, a blend of a straight filming amine with a neutralizing amine and emulsifiers provides a superior film bond, reduces deposit problems and provides better and more economical system coverage [3].

Yet another option for abating corrosion in condensate systems is the use of DEHA as a metal passivator and O_2 scavenger. DEHA converts loose, unprotective iron oxide (red hematite) deposits on the condensate pipe's inner surfaces to a black magnetite protective film, ferrous oxide magnetite (Fe_3O_4). The following is the chemical reaction for this conversion [1]:

$$4(C_2H_5)2NOH + 6Fe_2O_3 \leftrightarrows 4Fe_3O_4 + 4CH_3COOH + 3H_2O$$

The magnetite layer on the metal surfaces reduces corrosion rates from O_2 and carbonic acid. DEHA is usually dosed along with a neutralizing amine, as it is most effective at a pH higher than 8. DEHA has a high distribution ratio due to its high volatility, and hence provides effective protection by directly dosing it into the boiler feedwater instead of into the steam header. Due to the high distribution ratio, DEHA also spreads more effectively to the entire steam and condensate system [1].

Boiler makeup water that is low in alkalinity helps in reducing carbonic acid corrosion in condensate systems. Also, less amine addition is required. Dealkalizers and reverse osmosis can be considered for the treatment of boiler makeup water to reduce alkalinity.

When condensate in the piping is near its saturation temperature, carbonic acid formation is minimized, as the solubility of CO_2 in the condensate is low. However, if the temperature of the condensate is below the saturation temperature, likely due to improper insulation of the condensate lines, more CO_2 goes into solution, causing potential carbonic-acid corrosion. Therefore, it is important that condensate return lines are properly insulated and that the integrity of the insulation is maintained during the lifespan of the steam-condensate system.

Monitoring corrosion

Monitoring corrosion in condensate-return systems allows for early detection of problems — when the problems are still minor. If these problems go unnoticed, they can very soon become major problems, leading to leaks, plugging of condensate lines or catastrophic boiler-tube failure. Without proper corrosion-monitoring procedures in place, steam systems can have underlying issues that persist for long periods of time. Depending on the treatment method, condensate monitoring can vary, but generally, the following tests are required:

1. pH testing at various locations in the condensate system
2. Measurement of iron levels in the condensate
3. Measurement of residual amine in the condensate
4. Corrosion coupons

Evaluating pH. It is necessary to test the condensate's pH to determine if it is high enough to prevent carbonic-acid corrosion from occurring. Condensate pH measurement should be carried out at more than one location, to ensure that carbonic acid does not attack differently in separate sections of the system. This can happen when neutralizing amines with low distribution ratios (like morpholine) are used with multiple condensation sites.

While collecting condensate samples, it should be ensured that exposure to air is minimized, and that the pH test is run as quickly as possible. Also, the sample should be well cooled — otherwise, CO_2 and amine can both flash off of a hot sample, altering the pH. A pH of 8.3 or higher should be targeted.

Iron measurement. Iron, as a corrosion byproduct, is an indirect indicator of either low pH or the presence of O_2 somewhere upstream of the condensate sampling point. If this area is not being checked for pH measurements, iron measurement should be done. The sample should be from a continuously flowing stream to avoid a slug of iron oxide from the opening of a valve. A valve which is opened from a closed position (while taking a sample) can release a slug of iron which was sitting upstream of the closed valve. There are three different tests that can be run, for which proprietary methods of testing are available.

- The suspended-iron test measures insoluble suspended iron by passing the sample through a membrane filter. Suspended iron, mostly ferric iron (Fe_2O_3 or Fe_3O_4, which is Fe_2O_3 + FeO) is the result of an oxidizing condition in the condensate. The point of this test is to indicate the presence of O_2 in the system, either through improved deaeration or the use of better O_2 scavenging in the boiler. Suspended iron levels in excess of 50 parts per billion (ppb) are indicative of serious corrosion
- The total ferrous and ferric iron test measures both dissolved iron (mostly ferrous) and suspended iron (mostly ferric). If a membrane filter is used to remove the suspended iron, the test will measure dissolved iron. For most industries, a test result of 0.5 parts per million (ppm) is considered a good test result
- The total iron test allows for tracking total iron over time without regard for oxidation state. This test provides valuable feedback about the effectiveness of the amine treatment program of the condensate

Without proper corrosion-monitoring procedures in place, steam systems can have underlying issues that persist for long periods of time.

Residual filming amine and O_2 scavengers. If a filming amine is utilized, the residual should be measured. As stated earlier, the most common filming amine for boilers is octadecylamine. It should be measured on a steam sample — not a condensate sample. Dosage can be controlled to give 0.2–0.6 ppm octadecylamine in steam. Octadecylamine is most effective in condensate with a pH range of 6 to 8. Thus, the product may require supplemental neutralizing amine to be added. A cooling coil is required during sampling to prevent steam from flashing off, which will concentrate the amine in the sample.

Similarly, O_2 scavenger concentration must be precise within the system. If DEHA is used, a residual of 100–150 ppb should be targeted [5]. This residual quantity will take some time to appear, as the DEHA will initially be consumed in passivating the system. A cooling coil should be used for collecting the sample to avoid loss of volatile chemicals if there is steam flashing.

Corrosion coupons. Pre-weighed strips of metal (coupons) with very similar composition to the metallurgy of the condensate system can be used to monitor the corrosion rate. Corrosion coupon racks that hold three coupons are generally used. One coupon is exposed for 30 days, one for 60 days and one for 90 days. The coupons are removed for each time interval, and the weight loss of the coupon is determined. From the observed weight deterioration in the coupon, the corrosion rate is calculated in mils (0.0001 in.) per year (mpy). ■

Edited by Mary Page Bailey

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Prevent Combustible Dust Explosions with N_2 Inerting

Targeted use of blanketing with inert gas offers an effective strategy for preventing combustible dust explosions in CPI facilities

Bridget Nyland
Air Products
Tom Lee, Mitch Lund and Michael Thiel
Nol-Tec Systems, Inc.

IN BRIEF

REGULATIONS EXPAND DUST HAZARD SCOPE

COMBUSTIBLE DUST FUNDAMENTALS

INERT GAS FOR DUST

EXAMPLES

ECONOMIC ANALYSIS

Combustible dust is a critical safety concern for the chemical process industries (CPI). The use of nitrogen gas as an inert blanket offers an effective approach to preventing combustible dust explosions by displacing the oxidant required for an explosion. Nitrogen inerting is a practical solution to help prevent the devastation to personnel and property that can result from combustible dust explosions. Moreover, while nitrogen is not the right solution for every system, when properly designed and installed, it is often safer, less expensive and easier to maintain than alternative mechanical solutions. Using a set of examples, this article explores how nitrogen can be used to prevent — not just mitigate — combustible dust explosions in CPI facilities.

Regulations expand dust hazard scope

In December 2015, the Occupational Safety & Health Administration (OSHA; Washington, D.C.; www.osha.gov) will begin fully enforcing its new Hazard Communication (HazCom) standard, which adopts the Globally Harmonized System for the Labeling and Classification of Chemicals (GHS). Originally announced in 2012, the standard impacts a wide cross-section of industry sectors. One of the most significant changes in the new standard involves combustible dust. With the new HazCom standard, manufacturers will need to include combustible dust hazards in HazCom labeling, as well as in hazard evaluation and planning [*1*].

As a result, many chemicals not previously classified as hazardous will be officially designated as combustible dust hazards and will require adherence to NFPA 654, the combustible-dust explosion protection standard of the National Fire Protection Association (Quincy, Mass.; www.nfpa.org). While housekeeping and dust mitigation are recommended as a primary step to prevent combustible dust explosions, NFPA 654 also recommends explosion-mitigation devices to control explosions and limit damage. For example, the standard recommends including blowout panels in baghouses to release pressure from an explosion, or inline suppression systems to quickly extinguish an explosion or fire. However, these recommendations still leave the process fundamentally unsafe by only dealing with the explosion rather than preventing it. A safer way to comply with NFPA 654 is to use targeted nitrogen inerting rather than mechanical relief and suppression devices in selected areas.

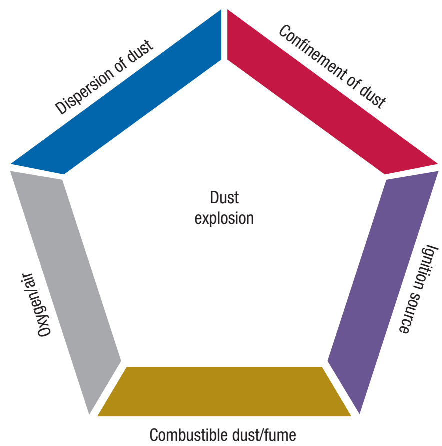

FIGURE 1. Five elements are required for a dust explosion to occur. Nitrogen inerting targets the oxidant by displacing it

Combustible dust fundamentals

While a triangle of required ingredients determines whether or not a fire can be sustained, combustible dust explosions are governed by a pentagon of interacting factors: oxygen, fuel, containment, ignition and dust dispersion (Figure 1). If one side of the pentagon is eliminated, an explosion is not possible.

Most materials can explode under the right conditions. In fact, it is easier to identify the materials that will not combust. OSHA's National Emphasis Program (NEP) on combustible dust defines the term as, "A combustible particulate solid that presents a fire or deflagration hazard when suspended in air or some other oxidizing medium over a range of concentrations, regardless of particle size or shape."

Defining which particulate matter presents a deflagration hazard requires specific laboratory analyses of several properties that are essential to determine the severity of a combustible dust hazard for a given material. These properties include, at a minimum, the limiting oxygen for combustion (LOC), minimum ignition energy (MIE), minimum ignition temperature (MIT), and the layer ignition temperature (LIT). Specialized laboratories can conduct these material characterizations and offer analysis of the resulting hazard.

Several parameters define a material's properties with regard to its combustibility. In terms of particle size, 425 μm (40 mesh) is generally defined as the limiting size to classify a material as a "dust," although certain materials with high surface area (such as fibers) may be combustible above that size threshold. A material's *Kst* (dust deflagration index) provides an indication of the severity of a dust explosion hazard. NFPA classifies dusts by *Kst* value. A dust is only considered inert with a *Kst* value of 0. Class 1 dusts are rated below 200 Kst, Class 2 dusts range from 200 to 300 Kst, and Class 3 dusts are rated above 300 *Kst*.

The minimum explosive concentration (MEC) is the limiting dust concentration to create an explosive atmosphere. The MIE and MIT are values used to define explosive conditions for particular materials. Table 1 contains the applicable dust properties of some common materials.

Following laboratory analysis, manufacturers will be able to determine the severity of the combustible dust hazard and document whether, in fact, the dust is not combustible. However, the majority of dusts are combustible, so most manufacturers will use these properties not to define whether the dust is combustible, but rather to define the severity of the hazard.

Several high-profile accidents have recently raised the awareness of this hazard in the manufacturing industry. For example, in 2008, 14 people were killed and 44 people were injured at one of the largest industrial incidents at the Imperial Sugar factory in Port Wentworth, Ga. Sugar dust that had built up to explosive concentrations in the factory ignited, sending a fireball cascading through the building. Many dust explosions have occurred with seemingly innocuous materials, such as organic compounds like sugar.

Following the Imperial accident, OSHA began focusing on the dangers of combustible dust explosions. In 2008, OSHA launched its NEP on combustible dust. Using the General Industry Standard 29 *CFR* 1910, Section 5(a)(i) of the Occupational Health and Safety Act (commonly known as the "general duty clause" [*2*]), along with generally accepted good practices, such as NFPA 654, OSHA began conducting extensive inspections in facilities containing dust.

In 2009 alone, 1,000 inspections were completed, and over 4,900 violations were issued for non-compliance, including poor housekeeping, inadequate hazard communication, and inadequate hazard control [*3*].

To date, most of the regulatory and industry focus in designing systems to handle combustible dust has addressed either the dust itself (through housekeeping initiatives), or the confinement of explosions. For explosion confinement, systems are designed so that energy can be released in a controlled manner. Examples of this type of control include blowout panels on silos or overdesigning ducting to withstand the force of an explosion. However, such measures focus on mitigation — the explosion still occurs. One of the safety infractions commonly cited by OSHA combustible dust inspectors are knock-out panel reliefs that vent to areas where employees are working. In such cases, the severity of the explosion may be mitigated, yet the risks of personnel injury still remain.

The case for inert gas for dust

Gas inerting represents an alternative approach, and works by disrupting the oxidant side of the dust-explosion pentagon. Insufficient oxygen means no combustion. Note, however, that there are some chemicals, such as peroxides, that contain bound oxygen and could still present a fire of explosion hazard in the absence of oxygen gas. For those chemicals, additional safety steps, including close control of temperature, are required.

TABLE 1: *KST* VALUES OF COMMON MATERIALS

Common Dusts	*Kst* Value
Activated carbon	44
Aluminum powder	400
Barley grain dust	240
Brown coal	123
Cotton	24
Magnesium	508
Methyl cellulose	209
Milk powder	90
Polyurethane	156
Rice starch	190
Silicon	126
Soap	111
Soybean flour	110
Sulfur	151
Toner	145
Wood dust	102

The CPI has been using inerting to eliminate fires from flammable materials for years. Fires require the presence of oxidant, fuel and heat (the fire triangle). For every chemical, there is a minimum level of oxygen required for combustion, called the minimum oxygen concentration (MOC), measured in percent oxygen. For decades, chemical manufacturers have been mitigating their fire risks from flammable materials by blanketing tanks and reaction vessels with nitrogen to reduce the oxygen content below the MOC. A similar methodology can be transferred to combustible dust explosions, where the inert-gas approach has not been typically applied.

The reasons for industry resistance to inerting boil down to three main perceived issues: nitrogen cost, safety and practicality. In reality, the perceived disadvantages can be easily overcome.

Cost. The cost of inert gas can be reduced in several ways. Depending on the application, inert gas use may be targeted to selected units or processes. Alternatively, the MOCs of many combustible dusts do not require 99.99% pure industrial grade nitrogen from a liquid nitrogen source. By using lower-purity nitrogen — such as 95 or 98% pure

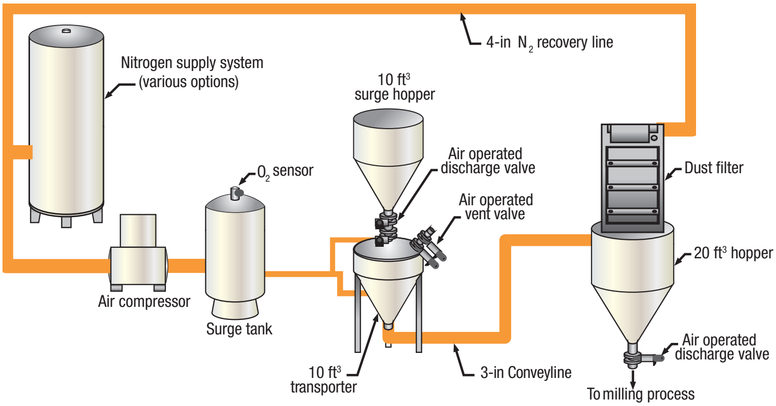

FIGURE 2. The pneumatic conveying system depicted here is equipped with traditional mechanical protection systems for combustible dust, including explosion-detection systems and blowout panels

nitrogen, such as that generated by a membrane or pressure swing adsorption (PSA) system — total nitrogen operating costs can be reduced. NPFA 69 and 654 provide guidance on determining the MOC for a combustible dust and the required nitrogen purity for safe inerting.

Safety. Asphyxiation risks are managed with basic safety training and simple engineering controls, such as O_2 monitoring and O_2-concentration control, as well as restricting inerting to appropriate areas.

Practicality. Maintenance on the nitrogen system is typically handled by the nitrogen provider and not by the end user. Nitrogen systems are in fact not all that maintenance-intensive, and unlike explosion detectors they do not require quarterly inspections.

Potential dust-related applications of nitrogen inerting include closed-loop pneumatic conveying, hopper storage, shredders, reactors, tanks, vessels and enclosures. Through smart design, inerting systems can eliminate the possibility of an explosion, increase worker safety, and provide a more cost-effective solution relative to other mechanical-protection systems.

Example 1. Plastic powder

Plastic powder coatings require a very fine powder to ensure a smooth coating when applied. The powders are created by pneumatically conveying plastic pellets into a mill for fine grinding. Particle sizes less than 100 µm (140 mesh) are frequently required for coating production.

Polyethylene (PE) is the most common plastic used in powder coating manufacturing, but polyvinylchloride, polyester and polyurethane compounds are also common. At particle sizes less than 100 µm (140 mesh), these plastics are highly combustible. In fact, PE powder is among the most common fuels for combustible-dust explosions because of its broad usage and its combustibility.

For example, fugitive PE dust caused an explosion at the West Pharmaceutical plant in Kinston, N.C., in 2003. According to the Proceedings of the 5th International Seminar on Fire and Explosion Hazards, the PE was used in a slurry to coat rubber parts, and fugitive PE dust from dried slurries accumulated in the suspended ceilings and cooling air ducts. A spark from a mill motor caused the dust to ignite, sending a flame propagating through the ducting. The ducting then overpressurized, sending the explosion front and burned dust into the suspended ceiling, which caused a larger explosion from the dust that had settled in the ceiling.

This case is particularly noteworthy because there was no previous accumulation of dust in the facility, due to top-class housekeeping practices. The facility had recently upgraded its dust-collection system and believed that the dust in the ceilings was inert based on previous laboratory testing. Indeed, investigative testing of the dust in the dust collectors indicated a largely inert dust. However, based on investigations following the explosion, only 280 lb of PE was required to produce the magnitude of the explosion felt during the incident. For a 10,000-ft^2 ceiling, that amounts to a layer of PE dust with a thickness of only 0.013 in. — about the thickness of four sheets of copy paper [*4*].

The explosion and subsequent fire resulted in six fatalities and multiple injuries. In the case of West Pharmaceutical, while it would be difficult to inert the ceiling ducting, it is quite possible that the mill itself could have been inerted, preventing the initial reaction. Either way, the incident highlights the significant danger of PE powder.

Economic analysis

One of the main misconceptions about nitrogen inerting is that it is much more expensive than traditional mechanical explosion-protection systems. In reality, on a total net-present-value (NPV) basis, nitrogen inerting systems are very comparable to reactionary mechanical systems and, in the case of even a small incident requiring cleanup with a mechanical system, the nitrogen inerting system is often more economical. The following example illustrates how the economics could

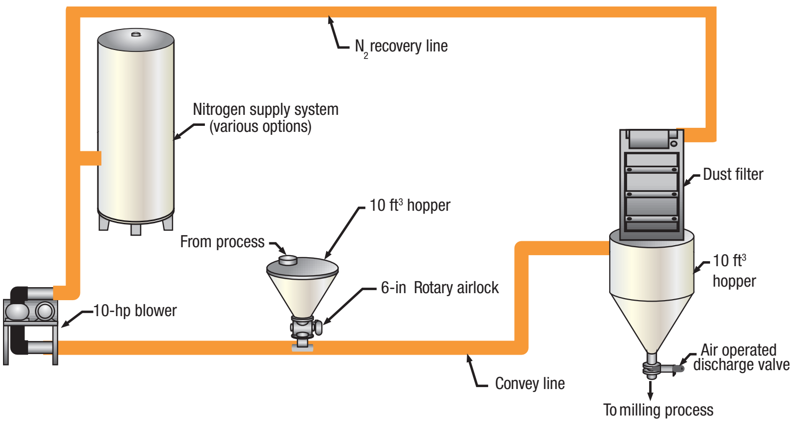

FIGURE 3. The pneumatic conveying system depicted here is protected by nitrogen inerting

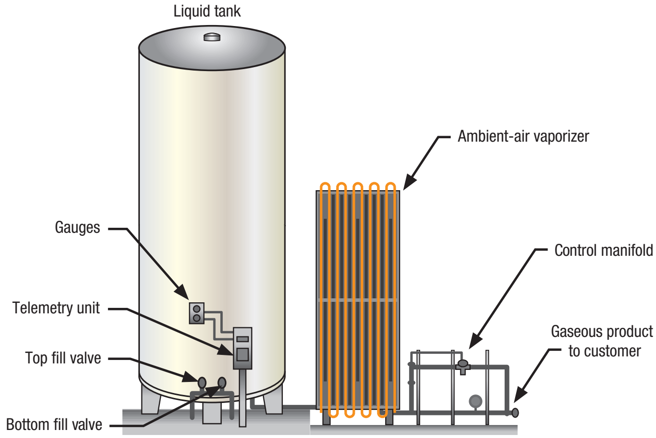

FIGURE 4. A typical bulk liquid-nitrogen supply system can be laid out as shown here

work. Consider a pneumatic conveying and milling system for PE-powder-coating manufacturing. Figures 2 and 3 show the two cases that were developed. In Figure 2, the system is protected using traditional mechanical combustible-dust protection systems, including explosion detection devices, suppression systems and blowout panels. Figure 3 depicts the system as protected by nitrogen inerting. Table 2 shows the technical specifications for the PE that was used in the case study models.

Both dilute and dense phase conveying conditions were modeled in the case study. Table 3 shows the process specifications for the cases that were modeled.

The nitrogen-protected system relies on the pressure of the nitrogen bulk tank to drive the pneumatic conveying process. A typical liquid-nitrogen bulk system can deliver gaseous nitrogen to house lines at pressures up to 200 psi without auxiliary compression. The vaporized gas is fed directly into the pneumatic conveying system. Figure 4 shows a typical liquid-nitrogen-supply system layout. The supply tank ranges in size from 60 gal to upwards of 11,000 gal to fit a wide variety of system needs.

To make efficient use of the nitrogen, a gas recovery unit was included in the system design. The gas recovery unit can recycle about 80% of the nitrogen used in conveying, drastically reducing the nitrogen consumption.

The mechanically protected system includes blowout panels for explosion protection. Please note that this is a basic explosion-protection system design, assuming an ideal plant layout for blowout panels. Depending on the working environment, system layout, and other safety considerations, additional explosion detection or suppression devices may be needed. The estimate includes one explosion incident in a five-year period requiring one week of downtime and cleanup. The incident-related costs include the time for lost production and related cleanup and replacement costs.

Tables 4 and 5 summarize the scope differences between the cases. The costs for each case are based on actual quotations for capital and maintenance, and current national U.S. averages for nitrogen and electric costs. An interest rate of 6% was assumed for the NPV calculation.

When comparing the estimated cost differences between these four scenarios, several observations can be made. First, for both the nitrogen-protected and mechanically protected dilute-phase systems, the capital costs are higher than the respective capital costs for the dense-phase systems. When looking at the mechanical protection case, the dilute conveying case requires a higher volume of air for the conveying medium. More air leads to higher severity in the event of an explosion, therefore requiring more robust explosion-prevention capital. When looking at the nitrogen protection case, the combination of the positive-displacement blower and airlock required for dilute-phase conveying is a higher cost than that of the gas-recovery compressor needed on the nitrogen dense-phase system.

Second, operating costs for the dilute-phase nitrogen system are higher due to the higher volume of nitrogen needed for the dilute-phase system. In this case, the dense-phase system concept requires less than 10% of the average air or nitrogen usage than the dilute-phase system concept.

Third, maintenance costs for the mechanical-protection systems are higher than those for the nitrogen-protection systems, mainly due to the costs of annual inspections required by the explosion-protection devices.

Finally, looking at the dense-phase conveying scenario and considering the costs from a small incident occurring once in five years, the nitrogen system is cheaper on a five-year, NPV basis. Because of the high gas flowrates required, the nitrogen system for the dilute-phase pneumatic conveying system is more expensive on a five-year, NPV basis.

However, beyond a simple NPV calculation, this exercise does not take into account all factors that should be considered when designing a dilute-phase pneumatic conveying system. For example, plant layout is an important consideration. Due to location in the plant, a system retrofit design would require much more explosion protection than a system that could

TABLE 2: TECHNICAL SPECIFICATIONS FOR POLYETHYLENE IN EXAMPLE 1	
Material	High-density PE
Flowability	Free-flowing
Density (aerated/loose/packed; lb/ft^3)	22.7/25.3/28.4
Kst	134
Material Description	Fine, subangular, flake/sliver/granular particles

TABLE 3: PROCESS SPECIFICATIONS FOR CONVEYING SYSTEM IN EXAMPLE 1		
	Case 1	**Case 2**
Conveying phase	Dense	Dilute
Production rate	400 lb/h	400 lb/h
Conveying length	400 ft	400 ft
Conveying pipe diameter	3 in.	3 in.

TABLE 4: COSTS REQUIRED FOR NITROGEN- AND MECHANICAL-PROTECTED SYSTEMS		
	Mechanical	**Nitrogen**
Capital costs	Blowout panels Explosion detection (optional) Isolation valves (optional) Suppression devices (optional) Air compressor (dense phase) Positive displacement blower (dilute phase) Rotary airlock (dilute phase)	Nitrogen system foundation Gas recovery unit
Operating costs	Compressor/blower electricity costs	Nitrogen Gas-recovery electricity costs
Maintenance costs	Quarterly inspections Annual inspections System preventive maintenance	System preventive maintenance
Explosion consequences	Assume system mitigates one explosion in five years. Assume explosion requires one week lost production and cleanup	Explosion is prevented with inerted system

be placed in an ideal location. Vents for explosion panels may require long ducting lines or secondary protection systems to prevent employee injury — a practice discouraged by NFPA 68 because shorter ducts decrease explosion severity. In certain retrofit cases, mechanical explosion protection can leave manufacturers with a difficult challenge in trying to meet code requirements safely.

Each incident will be specific to a manufacturer's particular product and protection system, so the cost and frequency of an incident occurring may vary. However, even small incidents may require plant downtime, replacement of protection systems, and cleanup of hazardous material. A nitrogen system greatly decreases the risk of any explosion happening at all, as well as any related expenses. In this case, an NPV difference of $100,000 is minimal in comparison to the total capital of a pneumatic system and the significantly reduced explosion risk that comes with an inherently safe inert system over the course of the system's life.

Example 2. Tire manufacturing

One industry that will be heavily impacted by the adoption of the GHS is the tire manufacturing industry. Under the new regulations, carbon black, a material used extensively in tire production, will be classified as a combustible dust. This will require tire manufacturers to review their existing processing plants and retrofit them to comply with NFPA regulations, potentially requiring expensive capital investments if traditional suppression controls are utilized.

However, tire manufacturing is an application that lends itself to nitrogen inerting because nitrogen is often already used in the tire curing process at many plants, where it is injected into the tire molds to cure the tires. Because the nitrogen is already onsite, it can easily be incorporated into a dust-control scheme using inerting without incurring additional installation costs. In addition, since the nitrogen used for curing can be recycled through the pneumatic lines, the nitrogen needed for curing easily supplies the need for inerting. This simple system removes the need to install mechanical retrofits to comply with NFPA 654. This system has been installed at large tire producers specifically to combat the dust hazards identified with the new classification of carbon black dust.

Example 3. Grain manufacturing

The food industry may be the most impacted with the new changes. Some of the most highly combustible dusts are found in the food manufacturing industry, with sugar and grain being two of the more notorious culprits. It is estimated that 150 people have died in food-related combustible-dust explosions in the last 20 years in the U.S.

Some components of a food processing plant are impractical to inert, such as grain elevators, but there are many contained areas that can be inerted safely and economically. Selective inerting as part of a combustible dust plan can reduce the cost of overall protection. Hoppers are a great example of how smart design can make nitrogen inerting possible.

The authors were involved with a recently designed and installed nitrogen-inerting system in a large biomass hopper with the aid of computation fluid dynamic (CFD) modeling. The CFD models provided precise estimates of the methane offgas concentration levels throughout the silo and guided the placement and orientation of nitrogen-injection nozzles throughout the silo (Figure 5). Rather than flood the silo with nitrogen, the hopper owner was able to apply nitrogen in locations and amounts that exactly matched what was required to prevent a dust explosion within a large space.

The same process could be used for smaller silos and hoppers in the food processing industry, as well as other storage containers. Closed-loop pneumatic conveying lines are another prime target for incorporating nitrogen inerting.

Beyond economics

Beyond the economics, there are several other qualitative differences between mechanical explosion mitigation and nitrogen inerting systems

TABLE 5: ECONOMIC DIFFERENCES BETWEEN FOUR DUST-EXPLOSION-PROTECTION SCENARIOS				
	Mechanical Protection		**Nitrogen Protection**	
	Case1 (dense)	**Case 2 (dilute)**	**Case 1 (dense)**	**Case 2 (dilute)**
Capital costs	$20,000	$35,000	$30,000	$42,500
Continuous operating costs	$15,000	$6,000	$25,705	$84,615
Annual maintenance costs	$8,500	$10,000	$2,500	$4,000
Lost production and cleanup costs	$147,800	$147,800	$0	$0
Five-year NPV	($216,000)	($201,000)	($137,607)	($354,500)

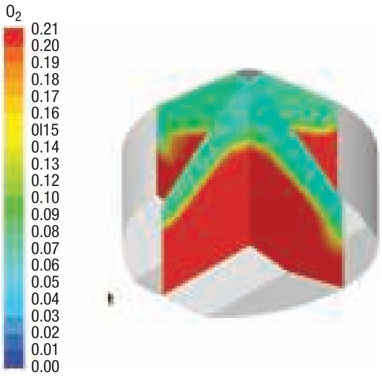

FIGURE 5. Computational fluid dynamics modeling can help pinpoint areas of oxygen concentration

that should be considered. First, from a safety perspective, the nitrogen system creates an inherently safe environment with regard to explosion protection, while the mechanical system reacts to the explosion. In the mechanical system, there are several modes of failure for the system, and components like blowout panels are difficult to test in order to confirm functionality. Further, testing suppression devices and explosion detection systems require a system shutdown. In contrast, there is only one failure mechanism for the nitrogen system: loss of nitrogen. A pneumatic conveying system can be driven by the pressure from the nitrogen system, so the system automatically shuts down with a loss of nitrogen supply.

For manufacturers who do not currently use nitrogen in significant amounts, one of the major concerns is the potential risk of nitrogen asphyxiation. Already used widely in the CPI, nitrogen can be implemented safely as long as proper procedures for storage, handling and use are followed [5]. Nitrogen should never be vented into a location where workers are present or into a confined space that could be unintentionally created. In addition, oxygen monitors must be installed to alert workers in the event of an oxygen-deficient atmosphere.

Implementing N_2 inerting

For manufacturers interested in implementing nitrogen inerting for dust safety, there are guidelines that can be followed.

Process design. Nitrogen inerting works best in certain enclosed or semi-enclosed areas, such as closed-loop pneumatic conveying systems, storage hoppers, vessels, dryers, spray dryers, grinding mills, granulators, shredders and mixers.

Nitrogen supply. Nitrogen requirements will vary greatly depending on the material being processed, production rate, process conditions, size of the vessels, number of use points, and MOC. All of the required flowrates can be supplied by a nitrogen system, but the mode of supply will depend on the average consumption, as well as on peak requirements and usage pattern. For example, at low flowrates, a microbulk system may provide the most cost-effective supply. For the highest flowrates, onsite nitrogen generation systems could be considered. In many cases, a nitrogen-recovery and recycling unit greatly improves the overall system economics to reduce nitrogen usage.

With any nitrogen system installation, an oxygen-sampling system needs to be installed to verify the atmospheric oxygen content. These systems must also be designed with adequate controls to ensure that the correct oxygen levels are maintained. Oxygen monitoring can also include built-in controls to provide protection for emergency inerting should the process conditions change.

Pneumatic conveying system. In general, a pneumatic conveying system should be considered in situations where there is limited footprint or flexibility. Pneumatic systems are much easier to install in an existing plant space because it is easy to route a small-diameter conveying pipe around existing equipment. Pneumatic systems are totally enclosed, resulting in excellent dust control, and they have few moving parts, which saves on plant maintenance costs.

In all cases, when considering whether to install a nitrogen-inerting system, it is important to understand your current process well, including the properties of the materials in your process and their associated combustible-dust hazards. With that knowledge in hand, nitrogen experts and pneumatic conveying experts can be a good resource in the design of a safe and economic nitrogen inerting system.

While there are many places where nitrogen systems can be designed practically, cost effectively, and safely, there are situations where nitrogen inerting does not work as well. For example, large dust collectors or ductwork are usually not conducive to nitrogen inerting because of high flowrates and large spaces. Similarly, bucket elevators are usually not practical for nitrogen inerting because of the large spaces, lack of containment, and worker presence. In such situations, diligent housekeeping is the key to reducing the risk posed by dust explosions.

OSHA's adoption of the GHS will require manufacturers in the U.S. to comply with many aspects of NFPA 654 for materials not previously considered combustible dusts. Manufacturers can choose to implement systems that mitigate the damage caused by combustible dust explosions, or they can choose to prevent combustible dust explosions from occurring in the first place. ■

Edited by Scott Jenkins

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Post-Combustion Carbon Capture Technologies

Several CCS processes hold much promise, and there are challenges yet to be met

Julie Horn and Raymond Zbacnik
Kiewit Power Engineers

IN BRIEF

CURRENT CCS REGULATIONS

ADSORPTION-BASED TECHNOLOGIES

ABSORPTION-BASED TECHNOLOGIES

MEMBRANE-BASED TECHNOLOGIES

ALGAE-BASED TECHNOLOGIES

COMPRESSION, TRANSPORTATION AND SEQUESTRATION

A number of post-combustion carbon capture technologies have the capability to reduce the amount of carbon dioxide emitted to the atmosphere from fossil-fuel-fired industrial and utility-power plants. Further interest has been placed in this technology in light of growing concerns about climate change. This article investigates a few of the more promising post-combustion carbon capture processes, including amine-based absorption, ammonia-based absorption, solid sorbent adsorption, membrane filtration and algae. This article also considers some of the challenges associated with compression, transportation and storage of carbon dioxide.

Carbon dioxide in the atmosphere is a greenhouse gas that most scientists consider to be largely responsible for climate change. Among the most significant sources of atmospheric CO_2 is fossil-fuel-fired power generation. For many years, technologies for carbon capture and sequestration (CCS) have been under investigation and development as a means of mitigating CO_2 emissions while still allowing industries to burn fossil fuels. Currently, three of the most promising techniques for CCS are being developed: post-combustion capture, pre-combustion capture, and oxy-combustion capture. Of these three, post-combustion CCS with amines and with chilled ammonia have had the most relative success and are discussed further in this article.

Current CCS regulations

Governmental support and regulations are needed to provide the incentive for CCS to become widely used in the chemical process industries (CPI) as well as the utility industries. Except for the case in which CO_2 is used for enhanced oil recovery (EOR) to increase the capacity of oil wells, CCS currently is not considered financially viable. For the power industry, the main reason is that CCS systems impose an energy penalty of up to 40% of the overall output of plants. When EOR is not feasible, it is not likely that the power industry will provide the investment to install capture systems without regulations or legislation that require carbon emissions reductions.

On June 25, 2013, U.S. President Barack Obama outlined a new national climate action plan that includes focusing on the use of cleaner energy and reducing carbon pollution. The President specifically called for the U.S. Environmental Protection Agency (EPA; Washington, D.C.; www.epa.gov) to complete new limitations on carbon emissions from both new and existing power plants. Following that, in September 2013, the EPA proposed a cap for CO_2 emissions for all new coal-fired power plants. This proposal would limit carbon emissions to 500 kilograms per megawatt hour (kg/MWh), which is about half of what average coal plants currently emit. The fundamental effect of this proposed rule would be that no new coal-fired power plants would be built, unless they had the capability for CCS. Furthermore, the November 2013 United Nations Framework Convention on Climate Change (UNFCCC) laid the foundation for a post-Kyoto Protocol agreement to be made in 2015. The 1997 Kyoto Protocol set international carbon-emission-reduction goals and includes two commitment periods. The first period sets a goal that the involved countries will reduce their carbon emissions to 5% below those of 1990. The second commitment period increases that margin to 18% below 1990 emission levels. After the second commitment period ends in 2020, the 2015 agreement will come into place. Reports on the UNFCCC meeting state that the new rule will focus on mitigation, adaptation, finance, technology readiness and transparency of action as it relates to CO_2 emissions.

On September 20, 2013, the EPA issued draft carbon-pollution standards for new power plants under Clean Air Act Section 111(b) New Source Provisions. The draft was published in the *Federal Register* on January 8, 2014. On May 9, 2014 the comment period closed with over 2 million comments.

EPA is still reviewing comments on the draft and intends to issue a final regulation in the summer of 2015.

On October 28, 2014, the EPA issued draft carbon-pollution standards for existing power plants. The draft was published in the *Federal Register* on November 4, 2014. After receiving over 2 million comments on the draft regulation, on January 15, 2015, the EPA announced that it would review and restructure the carbon pollution plan for existing power plants including revising the state targets for carbon pollution reduction. A new revised draft is expected in the summer of 2015.

Source: Folger, CRS Report [1]

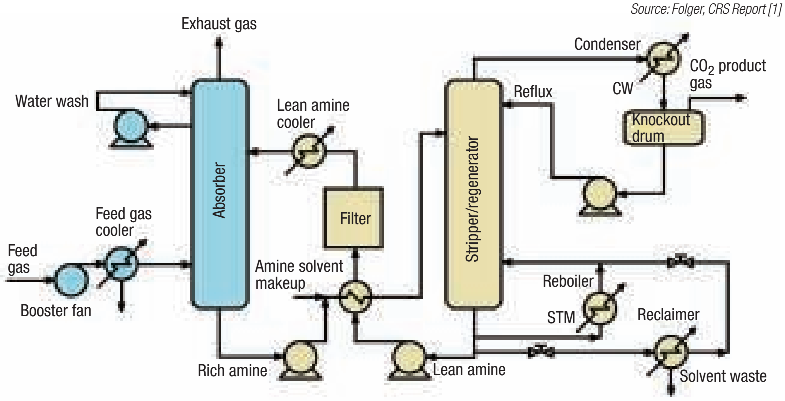


FIGURE 1. An overview of post-combustion, amine-based carbon capture is depicted here

Absorption-based technologies

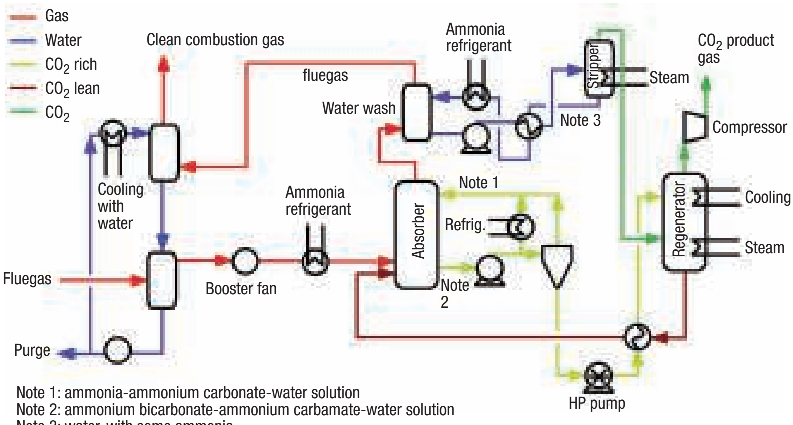
Amine-based. The CPI have had the most success with developing CCS technologies using amine-based solvents, such as monoethanolamine (MEA), diethylamine (DEA), methyl diethanoloamine (MDEA), piperazine (PIPA) and 2-amino-2-methylpropanol (AMP). Such chemical solvents have desirable properties in that they often react strongly and quickly with CO_2, yet they also release the CO_2 while regenerating the solvent. Amine-based solvents are able to remove large amounts of CO_2 from fluegas at low pressures.

The basis behind amine-based carbon capture processes is fairly simple (Figure 1). Fluegas from utility and industrial boilers typically contains mostly nitrogen (about 70 vol.%), smaller amounts of water and CO_2 (about 20%), and impurities of SO_2, NO_x, mercury and ash particulate matter. An air-pollution control system must be in place to greatly reduce the presence of these impurities in the fluegas before entering the carbon capture system. The cleaned fluegas then enters a small scrubber vessel to cool the gas and remove more trace sulfur impurities. From the quencher, the fluegas enters the absorber. The absorber uses the amine as a solvent to reduce the CO_2 level in the fluegas. This exothermic reaction typically removes about 85–90% of the CO_2 from the entering fluegas. The CO_2-rich solvent mixture is then sent to a heat exchanger before entering the regenerator. In the regenerator, the solvent is steam-stripped, causing the essentially pure CO_2 to come out of solution in an endothermic reaction. The overhead CO_2 is then compressed and fed to a pipeline, while the CO_2-lean amine solvent is recycled back to the absorber for reuse.

Ammonia-based. Ammonia-based CCS systems show promise for a number of reasons. As compared to amine solvents, ammonia solvents are less-expensive, have lower heats of reaction, and require less energy for regeneration. The use of ammonia could drive overall plant costs down as a result of ammonia's ability to simultaneously absorb multiple pollutants, such as CO_2, SO_2, NO_x and Hg.

A major challenge associated with ammonia-based systems is that of ammonia slip. Because ammonia is more volatile than amines, it can sometimes be released into the fluegas stream during absorption. If ammonia-based processes are to be economically viable, ammonia slip must be controlled to avoid the need for additional fluegas cleanup.

Alstom (Levallois-Perret Cedex, France; www.alstom.com) developed a process using chilled ammonia that has had success on the pilot-plant level. The process uses ammonium carbonate that has been chilled to about 20°C as the solvent to absorb the CO_2 from fluegas, which has also been cooled. The relatively low temperature in the absorber prevents significant ammonia slip from occurring. The overall system flow is similar to the amine-based systems: the CO_2-solvent stream is sent to the regenerator where heat is added to cause the CO_2 to come out of solution. Then the CO_2 stream may be compressed and stored, while the regenerated solvent is recycled to the absorber and used again. While the Alstom process has controlled the amount of ammonia slip by chilling the solvent and fluegas, there are very significant energy costs associated with this chilling. Therefore, ammonia-based processes must be optimized to minimize ammonia slip



Source: Folger, CRS Report [1]

FIGURE 2. The chilled ammonia process has had success on the pilot-plant scale

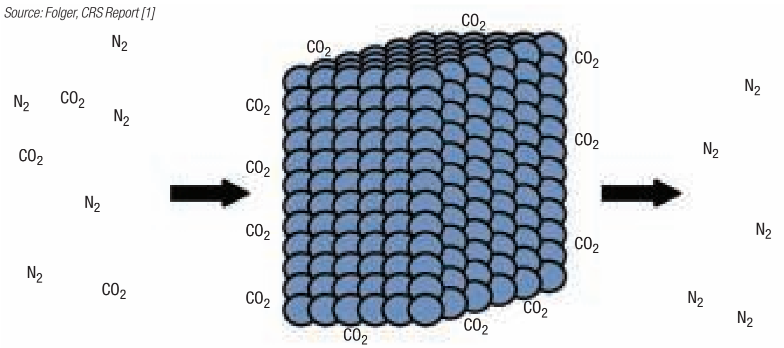


FIGURE 3. Solid sorbents for carbon capture work by adsorbing carbon dioxide onto their surfaces

in the most efficient way possible. Figure 2 shows an outline of the Alstom chilled-ammonia process.

Adsorption-based technologies

Solid sorbents work by adsorbing the CO_2 onto their surfaces (Figure 3). The sorbent is regenerated by changing the temperature or pressure, which causes the CO_2 to be released. Solid sorbents hold economic promise over amine-based CCS systems, because less energy is required in the regeneration step. There is no need for steam, and solid sorbents typically have lower energy requirements for sensible heating of regeneration gas than liquid water-based solvents. This means that less sensible heat is required to regenerate the sorbent.

Adsorption can be a physical or chemical process. Physical adsorption involves materials such as activated carbon, zeolites and metal organic frameworks (MOFs). Activated carbon is known to have a large inter-particulate surface area, thus increasing its CO_2 loading capacity. MOFs and zeolites are crystalline sorbents that capture CO_2 in their void spaces. Concerns about solids that adsorb physically include: selectivity in carbon capture, CO_2 carrying capacity, and physical degradation. Chemical adsorption is similar to the liquid absorption carbon-capture processes. The sorbent can be certain carbonates or amines supported on the surface of other materials, such as activated carbon. Amine sorbents supported on activated carbon have been shown in bench-scale tests to have high CO_2 carrying capacities and lower regeneration-energy requirements, since these systems lack water. However, care must be taken to prevent fouling and degradation over time.

Solid sorbents have their own associated challenges, which are different than those found with liquid solvents. As noted, care must be taken that the solid does not deteriorate over time. Solids are also more difficult to handle than liquids, which typically only require pumps. One key engineering challenge is designing a long-lasting sorbent that has a high surface area available for CO_2 capture, called carrying capacity. Engineers must also optimize the process to find the best method of handling solids, how to reduce regeneration-energy requirements further, the minimum possible pressure drop, and how to increase reaction rates.

Membrane-based technologies

Membranes are porous materials that filter CO_2 from fluegas streams. Gas streams are either pushed or pulled through membranes by a pressure differential. Pressure can be applied to one side of the membrane to push the gas through, or a vacuum can be created on the other side of the membrane to pull the gas through.

Membrane quality is determined by selectivity and permeability. Selectivity refers to a membrane's ability to filter one component (such as CO_2) rather than a different one (for example, N_2). Permeability denotes how much of a substance may pass through the membrane for a certain pressure difference. Permeability directly relates to the required membrane surface area needed for adequate CO_2 separation.

Research has been done on the laboratory and bench scale to improve membrane selectivity. In one line of research, an amine solvent contacts one side of the membrane to selectively absorb any CO_2 from the inlet gas stream that may have accidentally passed through the membrane. Another concept uses enzymes to mimic nature. A liquid membrane system uses carbonic anhydrase, the enzyme that transports CO_2 in mammal respiratory systems, to catalyze the transport of CO_2 through the membrane. However, membrane CCS systems encounter issues with fouling and scaleup for industrial settings.

Algae-based technologies

Because algae metabolize CO_2 to grow, algae ponds have been considered as a CCS method. In addition, waste heat from industrial plants could be used to warm the ponds in winter. Algae grow quickly and can be used for biofuels. The need for pond water is not of significant concern because many algae strains prefer salt water, meaning algae ponds will have no effect on potable fresh water demand.

There are, however, many challenges to overcome when considering algae for CCS. Algae do not take in CO_2 very quickly, thus mandating the need for huge, city-sized ponds to process a typical industrial plant's CO_2 output. In addition, the algal biofuel will eventually be burned, releasing its CO_2 into the atmosphere. Such an action reduces, but does not eliminate the carbon footprint associated with power production.

Compression, transportation and sequestration

Once the CO_2 has been captured, it must be compressed, transported, and either used or stored. The compression and transportation steps are mature technologies. Captured CO_2 is often compressed to about 140 bars so that it becomes a supercritical fluid and behaves like a liquid, making it possible to transport CO_2 via a centrifugal pump through a pipeline. The critical point of CO_2 is reached at 31°C and 74 bars. Therefore, if the temperature and pressure are maintained at about 38°C and 100 bars respectively, the CO_2 will still behave somewhat like a liquid and can be pumped to 140 bars for final disposition.

For the transportation of supercritical CO_2 in a pipeline, booster pumping stations can be placed along the pipeline to maintain sufficient terminal point pressure if needed. The transport of CO_2 through pipelines is a well-understood and safe practice. Carbon dioxide pipelines typically have very few leaks and have not caused any recorded injuries or fatalities. Carbon dioxide may also be transported by ship, but this is only done in small quantities.

Storage and use. It is the final step of CCS, the sequestration or storage of CO_2, that has resulted in the greatest controversy. Much of the captured CO_2 will be injected underground and stored with minimal leakage. Public opinion as of late has pushed for the practical use, rather than simple storage of the CO_2. For industrial boilers in CPI facilities, carbon capture can sometimes be used for the production of chemicals such as urea, methanol, formic acid, cyclic carbonates and polycarbonates. Carbon dioxide can also be used in the production of food and soft drinks. However, this consumption provides only temporary storage for CO_2 because much of it is immediately released into the atmosphere upon use. More permanent uses for CO_2 include the production of plastics, fertilizers, ceramics and new types of cement. Integration of CO_2 use in these areas is likely to take time, so other storage options must be considered.

It is expected that most captured CO_2 will be injected and stored underground. The ability to do this depends on the presence of appropriate geological formations that can hold the CO_2. Characteristics of an appropriate formation include sufficient volumetric capacity to hold the CO_2, the ability to prevent this CO_2 from reaching the atmosphere or potable groundwater sources, and the ability to accept CO_2 injection at rates comparable to those of oil-and-gas extraction in industry. Some formations that can have the ability to accept CO_2 injection include sedimentary rock, oil and gas fields, saline aquifers and coal seams. Underground injection is a safe practice, provided that the injection site is carefully selected, the injection operations are properly performed, and the CO_2 is monitored during and after injection.

Looking ahead

Carbon capture and sequestration are both likely to increase in importance in the near future. International focus on reducing carbon emissions has brought forth new regulations that enforce and promote CCS technologies. The most advanced CCS methods include post-combustion amine-based and ammonia-based absorption of CO_2, but other methods are being researched and developed as well. While the compression and transport of CO_2 is a mature technology, the storage and use of CO_2 have been a source of controversy. More research needs to be done in order to find additional ways to permanently use CO_2, and to ensure the safety of underground injection. ■

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For more on CCS, see CO_2 Gets Grounded, *Chem. Eng.*, April 2014 at www.chemengonline.com.

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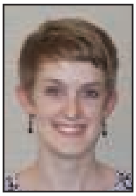

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Rotating Machinery: What You Should Know About Operational Problems

Follow this guidance to improve the operation, safety and reliability of rotating machinery in chemical process plants

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Troubleshooting problems in rotating machinery (such as compressors, pumps, steam turbines, gas turbines, turbo-expanders and more) can present difficult challenges during day-to-day operations in facilities throughout the chemical process industries (CPI). Reliable operation is an important factor in keeping plants running, particularly as plants push to operate at higher capacities. Lost profits due to persistent machinery problems can never be recovered.

Rotating machinery often presents the most difficult operational problems in a CPI plant. This article provides a practical, in-depth review of the art and science of machinery troubleshooting and problem solving. Five case studies are presented to cover a variety of relevant rotating-machinery systems, such as compressors, pumps, gas turbines and steam turbines. All of the case studies presented here were developed from actual field experience. This article offers a broad working knowledge of troubleshooting principles and practice, to help operators gain insight into different techniques and various methods for machinery problem solving.

A systematic approach

Proper CPI plant operation requires sustained attention to the following:

- Identifying opportunities to improve machinery reliability and safety
- Developing solutions for chronically problematic rotating machines

FIGURE 1. Shown here is a steam turbine dismantled for repair. This is the driver of the centrifugal compressor

A systematic approach is the key for solving any machinery operational problem. Comprehensive machinery assessments should be carried out using advanced data-collection tools and methods (Figure 1). For instance, the use of automated machine-data-collection software — which automatically collects a wealth of information specific to the machinery component — coupled with sophisticated modeling techniques, can provide great insight to support troubleshooting efforts related to complex rotating machinery. Such insight can help operators to diagnose the actual root causes of underperforming machinery and premature machinery failures.

When CPI operators rely too heavily on alarms and trips, there is limited time to take remedial action in response to a machinery issue. Instead, a proactive monitoring approach provides greater value, by enabling earlier machinery troubleshooting through improved early detection of unusual deviations. This can provide an earlier indication of problems that may be developing.

In modern operations, expert operators often opt to manage critical machine components using time-based data trends. Useful trends can be developed when the behavior of individual performance variables, such as pressure, temperature, flow, lubrication oil characteristics and more, are plotted over time on a graph. These trends can then be analyzed in conjunction with additional information, such as that derived from alarm screens and plant control-system graphics. By monitoring trends, operators can anticipate potential problems and propose smart solutions before any major upset occurs. Trends in relevant data can support operators and machinery engineers, allowing them to stay aware of situations as they begin to arise, diagnose the root cause of problems and resolve abnormal situations. The ability to gather and analyze trend data can also help operators to compare past and present behavior, thereby supporting efforts to anticipate future changes.

THE IMPORTANCE OF MONITORING

In one situation, a CPI company avoided an estimated $10 million in property damage and business-interruption loss in a year as a result of the early detection of high vibration levels in its rotating machinery. The high-vibration monitors indicated the deteriorating conditions (a developing problem) within a large, critical compressor train. The developing problem resulted in the loss of half of the bolts, a circumferential crack in the coupling spacer (about 80 mm long) and a radial crack emanating from the initial break at the time of shutdown.

If the fault had progressed and all of the bolts had sheared before operator intervention, the compressor would have been unrestrained — with potentially disastrous consequences. This clearly illustrates why, particularly in large CPI plants, it is vital to monitor critical components on a continuous basis.

Keep an eye on key variables

Vibration monitoring is an important indicator that can help operators to identify machinery problems at an early stage. The location of vibration sensors is vital, to avoid introducing errors during the measurement. In general, the best location for vibration sensors in rotating machinery is at the bearing or bearing housing (Figure 2). Vibration measurements at the machinery casing, in addition to bearing vibration, can provide useful data for identifying and solving machinery problems.

However, monitoring vibration alone is not sufficient to gauge the health of rotating machinery especially when large, critical machines are concerned. For instance, in a recent case, it was observed that one electric motor's temperature and current increased when the machine was overloaded — well before any vibration was detected. This underscores the importance of monitoring other parameters (such as temperature and current), in addition to vibration, to allow for early fault diagnosis of electric machines.

When vibration analysis is used alone, it may be difficult to establish the real cause of the vibration. In general, it is better to monitor both vibration and overall machinery performance (such as delivered pressure and flow in pumps or compressors) to obtain a more reliable fault diagnosis. And, it is important to realize that the vibration produced by the machinery is not a fault on its own — but rather a symptom (and early warning sign) of a developing failure condition.

Temperature is another critical variable, and the ability to monitor it accurately is of paramount importance in CPI plants. Today, a wide range of temperature sensors and measurement systems exists, including thermocouples, resistance thermal detectors (RTDs; also known as resistance thermometers), thermistors, filled thermal systems, pyrometers, infrared thermography techniques and glass thermometers. All are widely used to provide process and machinery temperature measurements.

The measurement of flowrate provides another useful indicator for the health of many processes and machinery systems. Traditionally, techniques based on differential pressure, turbine and vortex shedding have been used to measure fluid flowrate. However, these methods might not be suitable if an accurate measurement is required for gases, since errors can be introduced in the measurement due the compressible nature of gases. To use these methods with gas flows, it would be necessary to compensate for the gas density fluctuation in order to reduce the errors.

Modern Coriolis mass flowmeters are a more appropriate choice for measuring gas flowrate, which is usually independent of temperature, pressure, density and composition. This meter uses the Coriolis effect to measure the amount of mass moving through the element. In a simple form, the fluid to be measured runs through a U-shaped tube that is caused to vibrate in a perpendicular direction to the flow. Fluid forces running through the tube interact with the vibration, causing it to twist. The greater the angle of the twist, the higher the flow. These flowmeters have no rotating parts. Modern Coriolis flowmeters are highly accurate (providing accuracy to around ±0.5% of the mass flowrate).

For relatively low-speed rotating machines, vibration analysis may not be suitable to detect degradation or operational problems. However, acoustic-emission sensors, strategically located on the machine, can give operators early indication of deterioration in the machine's operating condition.

Control valves are vital components in every process and in many types of equipment packages where fluid is handled and regulated. However, the most common malfunction with control valves is internal leakage, which cannot be detected easily. Internal leakage can result from one of several factors, including an eroded valve plugs or seats, or insufficient seat load.

Five case studies

Case study 1: Insects in an air-compressor inlet filter. In a CPI plant in a remote area, insects caused problems for the inlet-air filtration unit of a large process-type air compressor. The accumulation of insects on the filters led to high differential pressure in the unit, leading to periodic compressor shutdowns. Multiple cases of surge and surge-related trips occurred because of this issue. Regarding a problem of persistent insects impacting the air-compressor, two solutions should be considered:

1. *A multi-sided insect screen*. For example, three-, four- or five-sided insect screens can be constructed (for instance, in a cube or similar configuration) in the front of the air filter, with a surface area roughly three to four times that of the front face of the air filter inlet. The rationale is that insects will gather on the larger-surface area of the screen (far from actual intake) and thus experience less intake air velocity, allowing them to fly away, reducing their opportunity to trap and plug the air filter. When a screen is built with three times the area of the air intake, the air velocity across the insect screen would be around 33% of the original velocity. When the

FIGURE 2. Tilting pad thrust bearings are widely used in relatively high-speed rotating machinery. These bearings are vulerable and can be damaged easily; shown here is one that was removed for repair

screen is built at four times the intake area, the air velocity across the screen would be just 0.25% of the original velocity.

2. *Specially designed pulse-clean filters*. Another possibility is to install pulse-clean filters that apply a periodic reverse pulse of air to dislodge the accumulated dirt and insects from the filter inlet at a pre-disposed differential pressure. This will require a specialized filter assembly with a compressed-air supply and associated equipment and controls. However, this solution is not usually recommended since this is a complex, expensive and risky option.

In this case study, the first proposed solution was used and a four-sided insect screen was built. For such an installation, the mesh size should be selected properly to stop the smallest anticipated insects from penetrating, and it should be reasonably rigid to allow for cleaning with a soft brush. If the mesh has a dense or tight weave (say, with holes around 1-mm dia.) to ensure that small insects cannot pass through, then it may be necessary to compensate with increased surface area (so that air intake is not impeded and pressure drop is not increased). For this case, a window screen mesh (with holes roughly 1-3-mm dia.) was selected. Routine inspections by technicians have been required to clean the screen. The structure of the insect screen was made rugged enough to resist wind and ensure longevity of the asset. This insect screen provides an added benefit, by helping to keep rain and dirt from being driven into the filter inlet by wind.

Case study 2: Discrepancies in performance maps. During the commissioning stage of a CPI plant, it was noted that there were two different sets of performance maps in the manual for a particular, critical centrifugal compressor — one from the compressor manufacturer and another from the anti-surge-system sub-vendor. The compressor had been delivered three years earlier but it was not installed and commissioned upon delivery because of a three-year delay in the project and a stop in the plant construction. Some of the engineers who had worked on this machine and associated unit had left their jobs and there was no proper documentation to clarify how this discrepancy originated.

At this facility, there were concerns about surge. During the initial period of operation, the compressor was tripped several times because of surge or other operational issues related to the existence of two different performance maps and the allowable operating range. Any attempt to identify which performance map and surge line were the most appropriate for use failed because of personnel changes at both the compressor vendor and the anti-surge- system sub-vendor during the 3-yr period.

In general, turbocompressors should be surge tested once they are installed, to develop accurate, as-built surge lines. For this machine, it was decided to perform the surge test at the site to identify the surge line and the correct performance map. This test was completed by hooking proper surge-detection hardware into the compressor's vibration-monitoring system. At each operating speed, the compressor discharge valve was slowly closed.

Prior to the surge, the surge-detection system (using vibration sensors as part of the compressor vibration-monitoring system) detected an increase in low-frequency vibration, which indicated the onset of surge. This was used to define the surge line. The compressor was not actually surged, just taken to the point of onset of stall. Once the as-built surge line was identified using this technique, it was seen to be different from what both the vendor and the sub-vendor indicated in their respective performance maps.

Often, it is common to obtain a site-tested, as-built surge line that differs from the vendor-calculated surge line, or even the shop-tested surge line, because of different compressor piping and arrangement in the vendor shop test compared to the final site installation. The site-tested, as-built surge line should be considered the most reliable data for any operator.

Case study 3: Re-rating a steam turbine. The steam turbine driver of a large pump train in a CPI unit created a bottleneck that prevented the unit from achieving a desired 5% increase in capacity. The operation team asked to run the steam turbine using 49-barg steam instead of 46-barg steam to achieve higher power generation from the turbine and higher pump capacity. Simulations showed that using 49-barg steam, it was possible to generate higher power, and this modeling also showed that the pump train could handle higher power and generate more flow within the pump curve. In fact, this investigation showed that the new pump operating point was a bit closer to the best efficiency point (BEP) than the old operating point. In general, significant engineering assessments are required in order to re-rate a steam turbine.

The steam turbine casing in this case was originally designed and rated to 46 barg. In order to increase the pressure rating, the design of the casing was checked by both the vendor's engineering team and an independent consultant. It was determined that it could safely and reliably contain steam at 49 barg. The casing was re-rated, after a proper hydro-testing, as per code requirements.

Using the same rotor, the pressure drop per stage was increased. The existing impellers were checked to ensure that they were strong enough and the rotor did not require changing. Simulations and investigations showed that diametric changes and changes to internal static components within the casing were not required. The steam turbine was re-rated for 49 barg. The steam-turbine-driven pump train has enjoyed smooth and trouble-free operation since re-rating after the changes were made.

Case study 4: Inlet filter for gas turbines. In general, gas turbines "ingest" different materials depending on the location and the plant — primarily dirt and dust, but also ice, rain, snow and salt. The cleanliness of a gas turbine is the key factor in its efficiency, reliability and safety. Accumulated dirt in the air-compressor section of a gas turbine can increase fuel consumption, and lead to more frequent maintenance outages and a decreased hot-section life.

At a given CPI plant, gas turbines were used to both generate power and drive the gas compressor. The original air filters were used in these gas turbine air-inlet systems, which mandated turbine shutdown and offline water washing every six months. The dirty air reduced the efficiency of the gas turbine fleet between cleanings. For instance, the gas turbine trains exhibited efficiency drop of as much as 2.5% on average in the three-month period before each offline water washing. The scheduled offline water washing every six months on each gas turbine of the CPI plant (just for cleaning), in addition to other outages for inspection and maintenance, was wasteful and non-productive. The operation team asked for a solution.

Getting maximum performance and reliability out of a gas turbine requires keeping the blades clean in order to reduce drag and improve the heat rate and power output. Inlet air filters play a significant role in the degree of fouling that gas turbines experience. With the original, older-style air filters, the operators of this plant were faced with a tradeoff: Installing higher-efficiency filters that remove more of the airborne particles creates a higher initial pressure drop and typically have a shorter life span compared to lower-efficiency filters. The filter pressure drop decreases the density of the air going to the gas turbine, which reduces the gas turbine's output power. Added pressure drop across the air filters increases the amount of energy needed to draw air into the gas turbine, which increases the gas turbine's heat rate.

In general, there are tradeoffs between efficiency, cost, filter life and pressure drop that all need to be considered when evaluating which air filters may be best for a particular operation. The small particles that cause most of gas turbine fouling are less than 3 micrometers (μm;

sometimes less than 0.5 μm) in size, below the standard capabilities of old-fashioned filters. Thus, emphasis should be placed on comparing the differences in filter efficiency for the removal of particles smaller than 3 μm (as well as considering filter efficiency on particles smaller than 0.5 μm) since those particle sizes generally contribute more to air-compressor fouling rather than larger particles.

Switching to better, higher-efficiency air-inlet filters is a good way to keep air-compressors cleaner, but they can offer some drawbacks. The most appropriate air filter should be selected with respect to the efficiency, the filter life and pressure drop. Today, new filter designs can keep the gas turbine clean with the same pressure drop and a better filter life compared to older-style filters. Today's modern filters have a structure and layers that allow for the effective capture of even the smallest particles (below 3 μm and sometimes below 0.5 μm) to keep the gas-turbine intake air clean without significant filter plugging.

There are tradeoffs between efficiency, cost, filter life and pressure drop that need to be considered when evaluating which air filters may be best for a particular operation.

Advanced hydrophobic high-efficiency particulate air (HEPA) filters have the same pressure drop as the older filters. However, the key to their improved filter performance is a novel multi-layer media construction that includes a hydrophobic membrane layer. Usually the first filter layer captures most of the airborne dirt. The middle layer — or layers — are most often made from expanded polytetrafluoroethylene (PTFE) membranes or similar, and they stop both submicron particles and water that may penetrate the first layer. Other layers are support layers added to provide strength and burst pressure resistance. These support layers give the filter more than twice the required burst strength of the old-fashioned filters. This extra burst strength prevents filters from breaking before they reach their expected lifespan.

Modern hydrophobic HEPA filters were installed for all gas turbines in this CPI plant. They completely eliminated the need to shutdown the gas-turbine trains for offline water washing. The operation has been satisfactory since the filter change.

Case study 5: Problems in turbine's steam-admission valves. In this case, problems in the steam-admission valves used to supply the steam turbine reduced the required steam flow into the steam turbine, which impacted the performance of a critical centrifugal compressor driven by the turbine, and this negatively impacted the plant's production rate. There were four poppet valves in the steam chest of this steam turbine. These should be staged to open at different load requirements.

Problems and issues for steam-admission valves have been reported extensively for steam turbines in different CPI plants. For any steam turbine governor or admission-valve issues, the following initial investigations are recommended:

1. Study the changes in performance of the steam-admission valve system and governor system
2. Evaluate the actual performance of steam turbine versus the design specification
3. Investigate the possible causes for discrepancies

Usually one or more of the following issues are reported for steam-admission valves:

- Insufficient nozzle-opening size
- Blockage inside the admission valve system
- Incorrect calibration of the admission valve system
- Problem with internal setup of the steam-admission valve system
- Gradual buildup of deposition or degradation products

Based on the steam-turbine manual for this unit, the governor should only be opened to around 78% for the first normal operating condition case. The investigation showed the position indicator on the governor was at 90% for this operating case (around 12% discrepancy). The initial suggestion was that the governor or steam-admission valves might not be correctly calibrated. The physical movement of the admission valves has not changed since commissioning, which indicated that the problem was not related to the gradual build-up of deposition or to degradation. A highly nonlinear relationship was reported at low valve-opening positions (around 0–20% of the rated flow). Below 20% of the governor position, there was very little steam flow through the steam turbine. This indicated that there was a problem with the first poppet valve.

There was almost zero increase in the steam flow once the governor position got higher than 91% of the rated flow. This was evident from the sharp drop-off at the end of the stroke-versus-steam-flow curve of the admission valve. There was also a problem with the last poppet valve. In other words, the lack of response during the first 20% of governor opening indicated a problem with the first poppet valve. The lack of response to the final 9% of governor opening indicated a problem with the last poppet valve. The steam-admission valve was overhauled for quick replacements of the first and last valves. The steam turbine operation has been satisfactory after this valve change. ■

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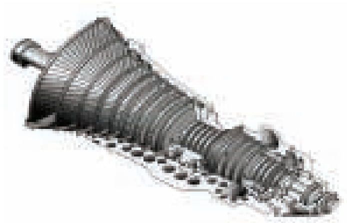

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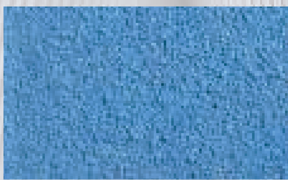

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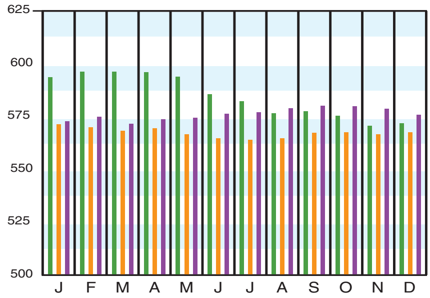
CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957-59 = 100)	Dec. '14 Prelim.	Nov. '14 Final	Dec. '13 Final
CE Index	575.8	578.4	567.5
Equipment	698.8	702.5	687.9
Heat exchangers & tanks	642.5	649.3	621.6
Process machinery	662.8	662.9	656.0
Pipe, valves & fittings	872.2	875.4	875.7
Process instruments	410.8	411.7	412.5
Pumps & compressors	943.4	942.9	925.8
Electrical equipment	515.2	516.2	513.8
Structural supports & misc	765.8	769.9	746.9
Construction labor	322.1	322.4	318.7
Buildings	546.4	546.9	532.8
Engineering & supervision	319.6	320.1	322.0

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:

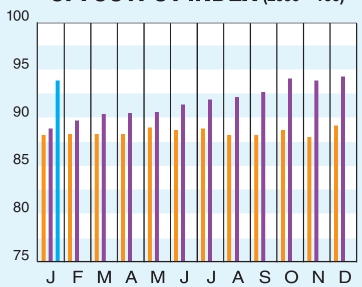
2006 = 499.6
2007 = 525.4
2008 = 575.4
2009 = 521.9
2010 = 550.8
2011 = 585.7
2012 = 584.6
2013 = 567.3



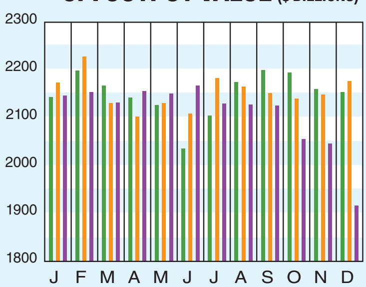
CURRENT BUSINESS INDICATORS

	LATEST		PREVIOUS				YEAR AGO	
CPI output index (2000 = 100)	Jan.'15 =	93.9	Dec.'14 =	93.5	Nov.'14 =	93.1	Jan.'14 =	88.8
CPI value of output, $ billions	Dec.'14 =	1,917.2	Nov.'14 =	2,024.2	Oct.'14 =	2,057.2	Dec.'13 =	2,177.3
CPI operating rate, %	Jan.'15 =	78.6	Dec.'14 =	78.3	Nov.'14 =	78.2	Jan.'14 =	75.1
Producer prices, industrial chemicals (1982 = 100)	Jan.'15 =	246.4	Dec.'14 =	271.0	Nov.'14 =	283.4	Jan.'14 =	295.8
Industrial Production in Manufacturing (2002=100)*	Jan.'15 =	102.1	Dec.'14 =	102.0	Nov.'14 =	102.0	Jan.'14 =	96.8
Hourly earnings index, chemical & allied products (1992 = 100)	Jan.'15 =	157.5	Dec.'14 =	157.3	Nov.'14 =	157.5	Jan.'14 =	157.9
Productivity index, chemicals & allied products (1992 = 100)	Jan.'15 =	109.2	Dec.'14 =	108.2	Nov.'14 =	107.6	Jan.'14 =	107.3

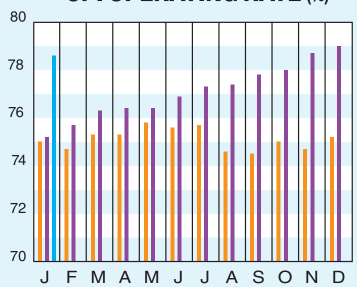
CPI OUTPUT INDEX (2000 = 100)



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.
Current business indicators provided by Global insight, Inc., Lexington, Mass.

CURRENT TRENDS

The preliminary value for the December 2014 *CE* Plant Cost Index (CEPCI; top; most recent available) inched downward compared to the final value for November, continuing a three-month trend. The index value sits at 1.45% above its level from December 2013. Meanwhile, updated values for the Current Business Indicators from IHS Global Insight (middle) show a very small increase for CPI output, but a decrease for CPI value of output. This is the second consecutive month for similar behavior in these categories. Producer prices fell in January.