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Editor's Page

Lessons learned

Back in the 1980s when teaching a physical chemistry (P-chem) laboratory at Gannon University, I devised a simple experiment to analyze the rotational band structure of carbon monoxide using our newly acquired Fourier-transform infrared spectrometer (FTIR). Having worked with students in the lab before and seen some of the mistakes they are prone to make, I preferred to avoid any and all risks associated with a cylinder of high-pressure CO in combination with a glass cell with fragile NaCl windows. So instead of using pure CO, we simply connected the IR gas cell to a vacuum manifold, slid a lit cigarette onto the rubber tubing attached to one of the stopcocks, and had the evacuated cell "take a puff" from the cig.

There was sufficient CO in that "puff" to measure its absorption spectrum, and the resolution of the FTIR was high enough to resolve the rotational bands of the CO, enabling the students to calculate all the nice things you can get from that — CO's rotational constant, its moment of inertia, the C–O equilibrium bond length, and even the temperature of the gas. Besides demonstrating the basic principles that the students were learning in the classroom, this simple experiment also had some lessons that I suspect were not forgotten, namely, that CO is one of many harmful byproducts of smoking a cigarette (other harmful substances could be identified by the "fingerprint" spectra of that one puff).

If I were teaching that course today, I would point out one additional lesson to be learned from the IR absorption spectrum of gases, namely, that water vapor and carbon dioxide — the main products of combustion and the dominating peaks in the IR spectrum of the "puff" — are also the main greenhouse gases (GHGs) in the earth's atmosphere, and their role as GHGs is because these two gases have strong absorption bands in the IR. It's fitting that the namesake for the FTIR spectrometer used for our little P-chem experiment — Joseph Fourier — first recognized in 1827 the importance of atmospheric gases on the rate at which electromagnetic radiation escapes into space. Just to drop a couple of more names: John Tyndall discovered, in 1863, that most of the IR opacity of earth's atmosphere was attributable to two minor components — H_2O and CO_2; and Svante Arrhenius first calculated (1896) the warming of earth due to CO_2 increase.

The point of this story is this: the greenhouse effect has been known for over a century, and although the complex relationship between GHGs and climate change is still being studied, the physics and chemistry of the phenomenon involved are well understood — today, it's "simply" a matter of fine-tuning our models.

Words like "myth", "hoax" and "conspiracy" should have no place in the scientific literature, the trade press or even the "main-stream media" in the discussions about GHGs. Demonizing, belittling or attacking those working on the climate models should not be part of the discussion, either. I strongly believe that it's the responsibility of chemical engineers — the masters of mass-and-energy balance and risk management — to contribute to, rather than hinder, the advancement of our understanding of the impact the rise in CO_2 emissions will have on our planet.

In his resignation letter to employees last month, U.S. Dept. of Energy Secretary Steven Chu wrote "the overwhelming scientific consensus is that human activity has had a significant and likely dominant role in climate change," and that "ultimately, we have a moral responsibility to the most innocent victims of adverse climate change." Because this page allows me to express my opinion, I will simply say, I agree, professor Chu. ■

Gerald Ondrey

Letters

CE scholarship applications open

Chemical Engineering is pleased to announce that applications are now being accepted for its annual Nicholas P. Chopey scholarship program.

Bringing recognition to the value of the chemical engineering profession, and striving to continually advance it, have been goals for this magazine since its founding in 1902. In late 2007, *Chemical Engineering* established the scholarship in memory of the magazine's former Editor In Chief.

Applicant qualifications. Applicants to the program must be current third-year students who are enrolled in a full-time undergraduate course of study in chemical engineering at one of the following four-year colleges or universities:

- Columbia University
- Rutgers University
- SUNY Buffalo
- University of Kansas
- University of Virginia

If selected as a recipient, the student will receive a one-time only award that may be used for undergraduate study.

Application details. Qualified and interested students must complete the application and mail it along with a current, complete transcript of grades to the following address, postmarked no later than April 15.

Nicholas Chopey Scholarship Program
Scholarship Management Services
One Scholarship Way, P.O. Box 297
Saint Peter, MN 56082
Telephone: (507) 931-1682

Application forms will be sent directly to the chemical engineering departments of the qualified schools and can also be found at www.che.com/npcscholarship/

Selection of recipients. Scholarship recipients are selected on the basis of academic record, demonstrated leadership and participation in school and community activities, honors, work experience, statement of goals and aspirations, unusual personal or family circumstances, and an outside appraisal. Financial need is not considered.

Selection of recipients is made by Scholarship Management Services, a division of Scholarship America. In no instance does any officer or employee of *Chemical Engineering* magazine play a part in the selection. Recipients will be notified in early June.

Donations. Checks should be made out to Scholarship America, with "Nicholas Chopey Scholarship Program" in the memo area, and sent to the following address prior to June 1, 2013:

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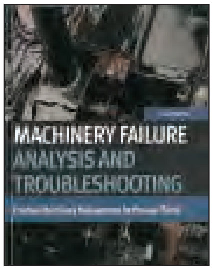

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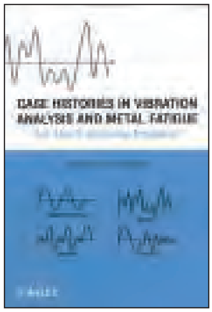

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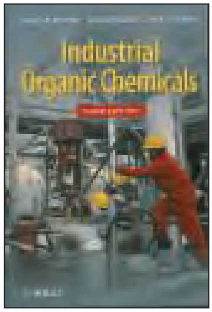

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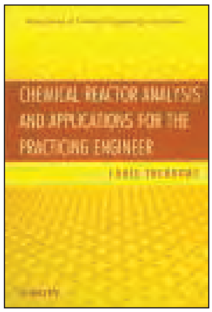

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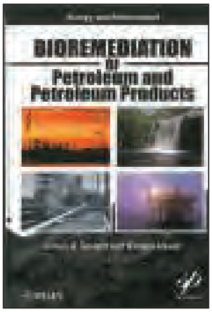

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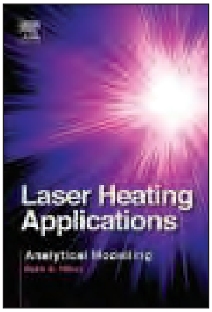

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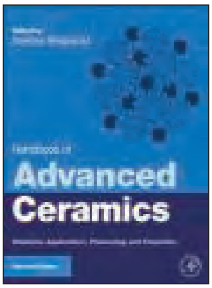


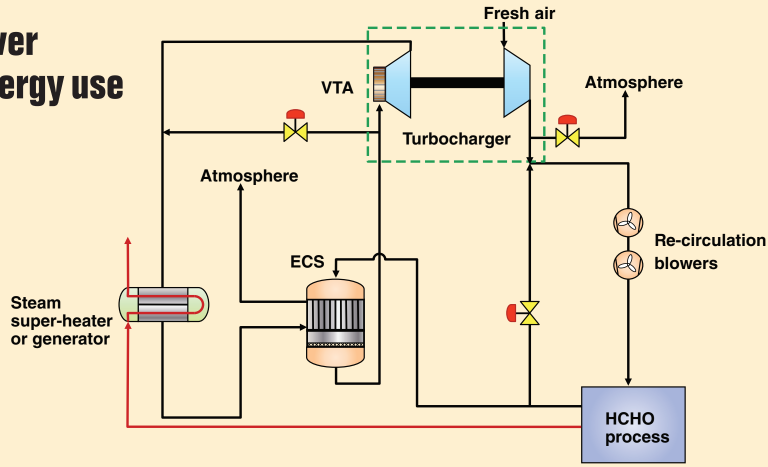
Scott Jenkins

Editor's Note: If you would be interested in authoring a book review for the *CE* Bookshelf column, please contact associate editor Scott Jenkins (sjenkins@che.com).

Chementator

Edited by Gerald Ondrey March 2013

Replacing a pressurization blower with a turbocharger reduces energy use



Reductions in power consumption by over 30% have been observed at a full-scale formaldehyde production plant by introducing a new design in which a pressurization blower is replaced by a turbocharger that is powered by the exhaust gas from the emission control system (ECS). The plant using this design was developed by Perstorp Formox (Perstorp, Sweden; www.perstorpformox.com), in cooperation with MAN Diesel & Turbo (Augsburg, Germany; www.mandieselturbo.com), and was installed and started up in mid-2012 at Egger Technologia Srl.'s plant in Romania.

The exhaust-powered turbocharger concept was awarded the Plant Innovation Award at last year's ChemInnovations Conference and Exhibition. The energy-saving turbocharger concept could be applied to chemical processes other than formaldehyde production. Formox now offers the design at new plant installations, as well as retrofits of existing plants.

Instead of a power-consuming pressurization blower in the formaldehyde process (see diagram), the developers used a turbocharger that originally was designed to power large diesel engines on ocean-going vessels. The turbocharger is driven by the pressure of the gas leaving the formaldehyde absorber and the heat generated when the gas is "cleaned" by the catalytic combustion within the ECS. As the turbine wheel rotates, it drives the compressor that is mounted on the same shaft.

The cost of powering the turbocharger is limited to a 30–40°C drop in the temperature of the gas leaving the ECS reactor, says Formox engineer Andreas Magnusson. "This translates into a 3–4% reduction in steam production, meaning pressurization is achieved more or less for free," he adds.

A recipe for improved Ti extraction from ilmenite

Existing metallurgical processes for titanium production from ilmenite — by far the most sought-after titanium ore — are plagued by disadvantages, mainly the generation of large amounts of waste, and improvements are needed to treat ilmenite for the production of high-grade TiO_2 pigment. Now, a group from CSIRO Minerals Down Under National Research Flagship and CSIRO Process Science and Engineering (Karawara, Western Australia; www.csiro.au) has developed a method for the recovery of titanium by the combination of direct leaching with solvent-extraction technology that overcomes some of the drawbacks of the traditional sulfate and chloride processes.

The group used two types of ilmenite from different locations in Australia with Ti/Fe molar ratios of 1.17 and 1.33. The samples contained up to 33% Ti (equivalent to up to 55% TiO_2), and up to 30% Fe.

The group found that the direct leaching of the ilmenite samples with HCl was much more effective with high chloride concentration in the feed solution. The presence of $CaCl_2$ was more effective for leaching than that of $MgCl_2$ and NaCl due to its higher solubility. The leaching efficiencies of Ti and Fe reached 96% and 97%, respectively in HCl-$CaCl_2$ solution, compared with 87% and 93%, respectively, when only HCl was used.

The optimum conditions for leaching ilmenite were found to be 5–7.5 M Cl^- solution with a total Cl^- concentration of about 500 g/L, 3.3 wt.% pulp density, 70–80ºC and 4–6 h of retention time. Under those conditions, the optimum leaching efficiencies were 99% Ti and 96% Fe for the first ilmenite ore sample and 94% Ti and 93% Fe for the second sample.

The leach residue, containing mainly unleached rutile and pseudorutile, can be used as a feed for the synthetic rutile production for further recovery of titanium in the residue.

Microelectrode

Although antimony electrodes have been used for decades to measure pH, they only allow for measuring pH changes at a certain distance from electrodes or corroding surfaces. Now, researchers from the Institute of Physical Chemistry of the Polish Academy of Sciences (Warsaw; www.ichf.edu.pl) have developed a way to make Sb microelectrodes, which enable measuring pH changes just over the surface of a metal where chemical reactions occur. As a result, the electrodes can be used for studying electrochemical and corrosion processes.

To make the microelectrode, a glass capillary is first filled with liquid Sb, then stretched to reduce the cross-section. Upon cooling, the thin tube is then cut flat. This electrode is said to be much simpler to use than commercial devices that require micromanipulators for precise placement of the electrodes.

Hybrid power plant

A hybrid thermosolar and biomass power plant has begun commercial operation in Les Borges Blanques, Spain. Said to be the first of its kind in the world, the plant is capable of producing 25 MW of power.

(Continues on p. 12)

Note: For more information, circle the 3-digit number on p. 64, or use the website designation.

A renewable source for methane

Conventional methanation — the reaction of CO and H_2 (synthesis gas) to form methane — has recently become important as a way to produce substitute natural gas (SNG) from gasified coal in regions of the world where natural gas is scarce (see *Chem. Eng*., August 2010, pp. 14–17). Now, an alternative methanation process, which produces CH_4 directly from CO_2 and H_2, has been developed by researchers from MAN Diesel & Turbo SE (MDT; Oberhausen, Germany; www.mandieselturbo.com).

The process takes place in a tubular fixed-bed reactor operating at about 260°C and 6–8 bars pressure. CO_2 and H_2 (mole ratio of 1-to-4) are fed into the reactor and react over a nickel catalyst to form CH_4 and H_2O. The water can easily be removed by condensation (and drying, if necessary), says professor Rolf Bank, head of R&D at MDT.

The process has been under development since 2009, and is now being tested at a pilot unit that started up in 2012 at the company's Deggendorf, Germany site. The single-tube pilot plant has a capacity of about 5 m^3/h, and has been shown to produce — in a single pass — 90–95 vol.% CH_4, with unreacted reactant gas the only impurity, says Bank. The tubular design also means the process is easily scaleable to any size, says Bank — simply add as many tubes as needed. Efforts to improve the yield have been underway in a three-year, BMBF-funded research project, which aims to optimize the process and improve the catalyst. Partners in the project include the Technical University of Munich, Wacker Chemie, Linde, Clariant (former Süd-Chemie) and E-On.

The process offers a way to produce carbon-neutral fuel (SNG) from renewable electricity, such as solar or wind, and could serve as a way to store energy by converting surplus electricity into fuel. The first industrial-scale demonstration of the process is a cooperative project with the VW Group and SolarFuel GmbH (Stuttgart, Germany; www.solar-fuel.net), in which "Audi e-gas" will be produced at Audi's Werite site. In the project, electricity generated from solar or wind will be used to electrolyze water into H_2 and O_2. This H_2, and CO_2 (from a nearby biogas plant) will be converted into Audi e-gas — enough to power 1,500 CNG cars over 15,000 km/yr.

A continuous process to make graphene . . .

An inexpensive and scalable process that uses supercritical (SC) liquids to make large quantities of graphene is being developed by the group of professor Itaru Honma at the Institute of Multidisciplinary Research for Advanced Materials, Tohoku University (Sendai; db.tagen.tohoku.ac.jp), in collaboration with Showa Denko K.K. (SDK; Tokyo, both Japan; www.sdk.co.jp).

The process features a flow-type loop reactor that enables continuous treatment with SC ethanol, which penetrates the graphite and causes exfoliation. SC treatment requires just 80 s, which is one hundredth the time required by batch reactors, says Honma. An 80% graphene yield is achieved after 48 exfoliation cycles of repeated adiabatic heating (to 400°C) and cooling in the loop reactor.

The researchers believe the new process is promising as a cost-effective method for mass-production of graphene, opening the door for next-generation electronics materials used for large-scale lithium-ion batteries and high-strength, low-weight electronic materials. SDK is now studying the possibility of scaling up the process for commercializing materials. Honma says first commercial products will require at least three years to develop.

. . . and graphene oxide is made in 'a microwave'

Microwave irradiation of graphite has been shown to produce graphene oxide with 90% yield by the research group of professor Yuta Nishina, Research Core for Interdisciplinary Sciences, Okayama University (Okayama, www.tt.vbl.okayama-u.ac.jp/archives/809). The yield is not only nearly twice that obtained by current synthesis methods (such as oxidation with hot sulfuric acid), but the reaction time is cut from 9 h down to 5 h. Nishina says the microwave synthesis is scalable, and could accelerate the development of new conductive materials without using precious metals.

(*Continued from p. 11*)

The solar component of the plant employs parabolic troughs to focus the sun's energy on heating a thermal fluid that is used to generate steam for power-generation systems. At night, and in low-sunlight weather, the plant operates by using timber and agricultural waste to fuel a boiler and generate steam. Thus the hybrid plant is able to operate continuously. The plant, built by Spanish partners Abantia (www.abantia.com) and Comsa Emte (both Barcelona; www.comsaemte.com), features a Marc-R steam turbine supplied by MAN Diesel & Turbo SE (Oberhausen, Germany; www.mandieselturbo.com).

Collecting fog

A treatment for cotton fabric that allows the cotton to absorb large amounts of water has been developed by researchers from the Technical University of Eindhoven (The Netherlands; www.tue.nl) and Hong Kong Polytechnic University (www.polyu.edu.hk). The fabric is coated with the polymer PNIPAAm [poly(*N*-isopropylacrylamide)], which has a sponge-like microscopic structure. At temperatures below 34°C, the coating is highly hydrophobic, allowing water to be extracted from fog and mist. The treated fabric can absorb up to 340% its own weight, compared to 18% for the untreated fabric. When warmed to over 34°C, the absorbed (pure) water is released. And the cycle can be repeated many times. This property offers potential applications in recovering water from fog or mist in desert or mountainous regions.

Accuracy boost

Sierra Instruments (Monterey, Calif.; www.sierrainstruments.com) has recently introduced its new QuadraTherm 640i/780i Thermal Mass Flowmeter Series, which is said to have the highest accuracy ever achieved for thermal-dispersion mass flowmeters. The 780i inline version, for example, achieves gas mass

(*Continues on p. 14*)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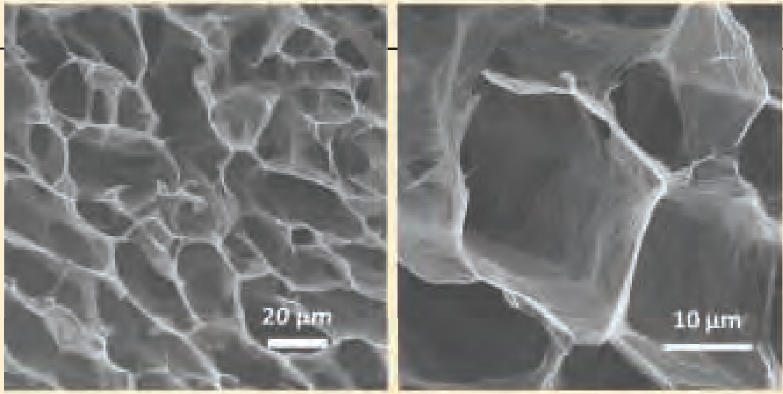

Making cork-like monoliths from graphene

A team from Monash University (Melbourne, Australia; www.monash.edu.au) has prepared graphene monoliths with a cork-like hierarchical structure, exhibiting ultra-low density, superelasticity, good electrical conductivity and high efficiency of energy absorption. The ability to maintain structural integrity upon large deformation is important for many emerging applications, such as flexible electronic devices, carbon-based biological tissue scaffolds, and ultralight cellular materials for mechanical damping and thermal/acoustic insulation.

Previously, several methods have been employed for constructing highly porous graphene cellular monoliths, such as chemical vapor deposition, but the resulting material is generally brittle and exhibits small recoverable deformation before failure.

Professor Dan Li says the team was particularly impressed by the high mechanical efficiency of natural cork's hierarchical structure. In cork, as well as in wood, cellulose nanofibers in the cell walls are closely packed in a highly ordered manner to maximize strength. Individual cells of tens of micrometers are intimately connected to form a honeycomb-like structure — maximizing the bulk-specific elastic modulus. The team therefore decided that graphene monoliths could deliver similar properties if they could be similarly structured.

The researchers showed that graphene monoliths with a cork-like hierarchical structure can be fabricated by freeze casting of partially reduced graphene oxide. The porous structure (photo) obtained by freeze-casting is governed by complex liquid-particle and particle-particle interactions. The team found that the amount of oxygen-containing groups of graphene oxide has a significant effect on such interactions. By carefully controlling both the amount of oxygen-containing groups of graphene oxide and freezing conditions, the team found that a cork-like graphene cellular structure (photo) could be obtained when the carbon-oxygen atomic ratio in partially reduced graphene oxide was tuned to about 1.93.

The graphene blocks produced are lighter than air, able to support more than 50,000 times their own weight, good conductors of electricity and highly elastic — able to recover from more than 80% deformation.

A bi-metallic nanocluster catalyst for highly selective asymmetric C–C formation

Shu Kobayashi and his research group at the University of Tokyo (Japan; www.chem.s.u-tokyo.ac.jp/users/synorg/index_e.html) have developed a ruthenium-silver nanocluster catalyst for the highly selective 1,4-addition reaction for the formation of asymmetric carbon-carbon bonds. Previously, the group had used its polymeric incarceration (PI) method to form metallic nanoclusters supported on a polystyrene-based polymeric matrix. Now, a very robust, highly selective catalyst has been developed with Rh-Ag nanoclusters supported on PI and carbon black (PI/CB Rh/Ag), which has been shown to be effective for the asymmetric 1,4-addition of arylboronic acids to enones.

The use of carbon black as a secondary support enhances the specific surface area, while Ag suppresses coagulation of Rh. The catalyst is less prone to leaching of metals (below detection limits) than predecessors, and can be recycled several times while maintaining high yields and excellent enantioselectivities, says Kobayashi.

In laboratory trials, asymmetric C–C bond-formation products were obtained from the reaction of cyclohexenone and phenyl boronic acid, using a toluene-water solvent. A 99% yield with enantioselectivity of 98% was achieved using PI/CB Rh/Ag after 6 h at 100°C. The versatility of the catalysts was also demonstrated by combining PI/CB Rh/Ag with the aerobic oxidation catalyst PI/CB Au for the one-pot, asymmetric 1,4-addition of an allyl alcohol and arylboronic acid. In this case, an 88% yield with enantioselectivity of 94% was achieved after 18 h at 100°C.

(*Continued from p. 12*)

flowrate measurement accuracy of ±0.5% of reading above 50% of full scale (air).

The series features a patented QuadraTherm sensor and proprietary iTherm algorithm set. Unlike traditional thermal devices that have two sensors, one for measuring temperature and another for velocity, the QuadraTherm uses four sensors — three Pt temperature sensors and one patented no-drift DrySense mass-velocity sensor. The QuadraTherm sensor isolates forced convection by calculating, and then eliminating, unwanted heat-transfer components, such as sensor-stem conduction — a major cause of false flow readings, says the company. This proprietary, "fundamentally different gas mass-flowrate calculation" leads to more precise, stable and accurate thermal mass-flow measurement, the company adds.

First field demo

Next month (April 30), the Fieldbus Foundation (Austin, Tex.; www.fieldbus.org) plans to conduct a series of live field demonstrations of its Foundation for Remote Operations Management (ROM) technology. This demonstration will be conducted at the Petrobras R&D facility (Cenpes; Rio de Janeiro, Brazil).

Said to be the first development of its kind integrating remote I/O, ISA 100.11a, WirelessHART, wiredHART and H1 fieldbus protocols into a single data management environment, Foundation for ROM extends the capabili-

(*Continues on p. 16*)

A cheaper way to destroy organic contaminants?

An ultraviolet oxidation process for the destruction of water-borne organic contaminants that combines UV with chlorine, rather than hydrogen peroxide, is being developed by MIOX Corp. (Albuquerque, N.M.; www.miox.com). The company's Advanced Oxidation Process (AOP) promises to be less expensive than traditional AOP treatment methods, says Susan Rivera, manager of research and development.

AOP combines UV oxidation with MIOX's main business — systems for the onsite generation of chlorine for water disinfection. In that process, food-grade salt is added to water, then the sodium chloride solution is passed through an electrolytic cell to convert the chloride ions to hypochlorite. In the new process, the hypochlorite solution is added to the water to be treated, prior to UV irradiation. The UV light produces highly reactive hydroxyl radicals that destroy small organic molecules in the feedstream.

In pilot tests at industrial and municipal water treatment facilities, the process has achieved complete removal of trichloroethylene (TCE) from a starting concentration of 15 ppb [parts per billion], says Rivera. The process has also attained a 65% removal of 1,4-dioxane from contaminated groundwater (from an initial 8 ppb), and complete removal of 2-methylisoborneol (MIB) from surface water, with an initial concentration of 96 ppt (parts per thousand).

The process promises to be less expensive than those that use H_2O_2 for various reasons, says Rivera. One reason is that chlorine is produced onsite. Moreover, only 5–10% of the H_2O_2 added in a conventional AOP is consumed, leaving 90–95% of the chemical unused at the end of the treatment process. Residual H_2O_2 has to be neutralized, often by the addition of hypochlorite. Using a grant from the National Science Foundation (Arlington, Va.; www.nsf.gov), MIOX plans to build a deployable pilot system, with an industrial partner, The purpose is to demonstrate the technology for industrial water reuse.

A step toward mineralizing CO_2 captured from fluegas

Researchers from Newcastle University (U.K.; www.ncl.ac.uk) have discovered that, in the presence of a nickel catalyst, CO_2 can be rapidly and cheaply converted into solid carbonate salts. The discovery could lead to a simpler and less-expensive alternative for carbon capture and storage (CCS).

Led by Lidija Šiller, a physicist and Reader in Nanoscale Technology, the researchers were investigating the detailed mechanism of the carbonic acid reaction (whereby CO_2 first dissolves in water, then reacts with

(*Continues on p. 16*)

MINERALIZING CO_2 (*Continued from p. 15*)

H_2O to form H_2CO_3), as well as how organisms — particularly the sea urchin — absorb CO_2 into their skeletons. "When we analyzed the surface of the sea urchin larvae, we found a high concentration of nickel on their exoskeleton," she says.

Armed with this clue, doctoral student Gaurav Bhaduri added nanoparticles of Ni to the carbonic acid test and found complete removal of CO_2. The researchers have subsequently analyzed the phenomenon and worked out the reaction mechanism, which was published in the January issue of *Catalysis Science & Technology*.

Up to now, the most promising catalyst for the hydration of CO_2 to H_2CO_3 has been the enzyme carbonic anhydrase, says Šiller, but biocatalysts are not only expensive, they are also pH- and temperature-sensitive. On the other hand, nickel nanoparticles are three orders of magnitude cheaper, operate at any pH and are also magnetic, enabling easy recovery for reuse, she says.

The group is now optimizing the mineralization reaction, focusing on two unit operations: the absorption column, in which CO_2 is removed from a gas stream by the Ni-catalyzed conversion to H_2CO_3; and the mineralization tank, in which H_2CO_3 is neutralized into a solid salt using silicates of calcium or magnesium.

As a CCS option, mineralization into stable, innocuous $CaCO_3$ or $MgCO_3$ is much simpler than injecting high-pressure CO_2 into underground aquifers (or depleted wells for enhanced-oil recovery), and also has none of the potential risks associated with injecting CO_2 into the ground. Šiller estimates the cost for Ni-catalyst-based CO_2 removal from fluegas at \$8 per ton of CO_2 captured (excluding the cost of silicates) — well below the \$20–50/ton of CO_2 for conventional amine-based absorption. ■

(*Continued from p. 14*)

ties of Foundation Fieldbus to numerous wired and wireless devices installed in harsh, remote locations. This open, non-proprietary solution provides a unified digital infrastructure for asset management applications ranging from tank farms and terminals to pipelines, offshore platforms and original equipment manufacturer (OEM) skids, says Fieldbus Foundation.

Graphene flagship

The European Commission (Brussels, Belgium) has chosen graphene as one of Europe's first ten-year, €1-billion, FET (future and emerging technologies) flagships. The Graphene Flagship will coordinate 126 academic and industrial research groups in 17 European countries with an initial 30-month budget of €54 million. The flagship is being coordinated by professor Jari Kinaret, at Chalmers University of Technology (Gothenburg, Sweden; www.chalmers.se). ❏

PROFESSIONAL BUREAUCRACY

California's PE Act continues to hinder chemical engineers from practicing their profession

Bob Katin, chairman of the California Government Relations Committee of the American Institute of Chemical Engineers (AIChE) and president of the California Legislative Council of Professional Engineers (CLCPE), is a persistent man. For more than 20 years he has fought to change the California Professional Engineers Act (PE Act) so that chemical engineers would have parity with civil engineers. In the course of that time, he has helped sponsor about a dozen bills, none of which was approved by the state legislature.

Katin, the owner of an engineering firm in Antioch, Calif. (www.katinengineering.com) is now taking a new tack. Frustrated by the legislature's unwillingness to change the law, he has embarked on a new campaign of informing high-level state and federal officials that they may not be able to carry out federally sponsored projects in California without breaking the PE law. This is because the Act gives civil engineers a virtual monopoly over infrastructure projects, he says, even in cases where they don't have the necessary expertise. On the other hand, hiring engineers that do have the expertise would break the law.

The basic issue is that civil engineers who pass the PE examination earn the exclusive right to practice their profession, which is broadly defined under the law. Mechanical and electrical engineers also get a license to practice their professions, but the definitions are much narrower. Chemical engineers and nine other disciplines simply get the right to use a title (for example, "chemical engineer"), but anyone can practice chemical engineering.

In other states, says Katin, licensed engineers are able to provide all engineering services within their area of competence, and 40 states do not indicate the discipline of the engineer on the license. "No other state in the nation has this crazy law that gives civil engineers a monopoly over all engineering and science," he says.

Katin got the idea for his new campaign from a fresh interpretation of the law by California's Legislative Counsel Bureau (Sacramento). The bureau's report concluded that only a licensed civil engineer can do engineering work on fixed sites, such as chemical plants and petroleum refineries. Only civil engineers may be "in responsible charge of designs, plans and specifications and engineering reports" for "fixed works." Professional engineers who sign engineering documents should be "capable of answering questions" on those documents.

The significance of the report, says Katin, is that a civil engineer has to do all the engineering work, not just oversee it. This interpretation also eliminates the "industrial exemption," under which chemical and other engineers employed by engineering and other companies do the work on a project, but the final documents are signed by a licensed civil engineer.

As a first step in his new strategy, Katin has settled on a planned multibillion-dollar high-speed rail (HSR) that will connect Los Angeles with San Francisco. The idea, says Katin, is to use federal pressure to change the law. "If you are taking money from the Federal Government you have to follow state law. For a start he has sent letters to Karen Hedlund, deputy administrator of the Federal Railroad Administration (FRA, Washington, D.C.), California Governor Jerry Brown, and Mark Paxson, general counsel in the State Treasurer's Office.

In his letters, he says that California law requires that anyone providing professional expertise needed for a railroad project must be a civil engineer, but HSR will require a number of engineering disciplines. Therefore, says Katin, the HSR project "will entail the need to violate the PE Act and require a breach of contract in order to be constructed." He received an acknowledgement from Paxson, who said he would "keep the letter in my file for consideration by disclosure counsel when the State decides to issue bonds for the High Speed Rail project."

As for the bills rejected by the California State Legislature, Katin says the bills failed because of strong opposition from Professional Engineers in California Government (PECG; Sacramento), a union of engineers and other professionals employed by the state. PECG has more than 10,000 members, and the majority of them are civil engineers.

Bruce Blanning, executive director of PECG, says, "it is not the case that the bills died because PECG killed them. PECG is not opposed to amending the Act and we want to find a solution"

The difficulty in making chemical engineering a practice act, says Blanning, is in defining specifically what chemical engineers do for the purpose of protecting public health, safety, welfare and property.

So far, most of California's chemical engineers are not affected by the law because they work for corporations and have "industrial exemption." Those most vulnerable are generally employed by small companies or work as independent consultants.

For example, E_2 environmental, a small company located in Irvine, Calif., worked for more than 14 years cleaning up the site of a former solvent- and oil-recycling facility before running afoul of the PE law. Under a contract with the California Dept. of Toxic Substances Control (DTSC, Sacramento) the company drilled a number of vapor-extraction wells and laid down an asphalt cap to prevent the vapors from getting into the atmosphere.

Over the years E_2 worked with a DTSC project manager and submitted several reports to him, says Dennis England, the company's CEO. However, the man retired about two years ago and the new project manager refused to accept the next report because it wasn't signed by a PE civil engineer.

"I told him our previous reports had not been signed by a PE civil engineer," says England, "but then his supervisor said we needed to have a PE civil engineer overseeing the work. I told the supervisor we have a class A engineering contractor's license with hazardous certification, but he still said the report was unacceptable." The company has not worked on the project for about 18 months, although its contract runs until the end of this year, says England. The project has been lying idle for about 18 months, although E_2's contract runs until the end of this year, says England.

To avoid such problems, E_2 and other companies sometimes hire a "token PE civil engineer" or a civil engineering contractor to help with a project. "The civil engineer may not understand the details of what we are doing, but our people do the work and he signs off on it," says one company manager.

Eric Anderson, a chemical engineer and engineering consultant in Pasadena, Calif., has a PE license in mechanical engineering, but not chemical engineering. "I didn't want to spend the time and money on a chemical engineering PE, which is essentially worthless," he says. The mechanical engineer's license, on the other hand, authorizes him to do more extensive work in his projects on industrial exhausts and air pollution control. "A mechanical engineer is a second-class citizen," he says, "but PE chemical engineers are third class and have no protection under the law."

On the other hand, another consultant, specializing in environmental engineering, health and safety, has been using his PE chemical engineering license for years to stamp the occasional document. "I've never been challenged," he says, "but maybe I'm just plain lucky." ■

Gerald Parkinson

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LIST USA

FIGURE 1. LIST Kneader Reactor technology provides key advantages to polymer manufacturers, such as process simplification, raw material costs reduction and energy savings, says the company

TRENDS IN POLYMER PROCESSING

Today's polymer and plastic processors face special challenges, but new turnkey systems can help

Because many of their products go directly to the ultimate end user, polymer and plastic processors are being asked to make their final products safer. Both consumers and governments alike are demanding that plastics, especially those that are destined for food contact, contain lower residual solvent and monomer levels. At the same time, the biopolymer industry is exploding and processors want to get in on the ground floor. However, because of the lower thermal stability, standard equipment isn't always the best choice for these applications. Also, a growing interest in recycled plastics is another new trend, requiring new technologies. In addition, polymer processors are asking equipment manufacturers to provide turnkey systems and better controls to assist in the production of better products in a more time- and cost-efficient way, using less energy. As a result, old-school machinery is getting a makeover that will help it better meet the needs of these new applications.

Solvents and devolatilization

"Many of our customers come to us with a request to help them achieve final products that have lower residual solvent levels or monomer levels," says Boyd Safrit, manager of R&D for North America with LIST USA, Inc. (Charlotte, N.C.; www.list.ch). "Processors are more frequently coming to us asking for higher conversions in reactors or methods that will remove more solvents at the end of the process."

Solvent removal is not without its challenges. In the past, processors heated up product in a single machine and were able to achieve low-enough levels. However, equipment manufacturers have had to devise new methods, systems and equipment to achieve even lower solvent levels.

For instance, LIST offers the Kneader Reactor (Figure 1) for bulk polymerization. LIST encourages bulk polymerization because it not only offers an effective method of devolatilization, but also because it's a cost effective and streamlined process. The Kneader Reactor offers an advanced shaft geometry that provides gentle kneading for minimal shear and maximum heat transfer. It enables operators to process high-viscosity and other hard-to-handle materials. The reactors allow producers to combine the separate steps of solution, emulsion and suspension polymerization into a single bulk-polymerization process, simplifying the manufacturing process, cutting raw material costs and saving energy.

The reactor also offers solvent-free bulk polymerization. During this process, conventional stirred-tank reactors require solvents to transfer heat and facilitate mixing of viscous mass. The solvents must later be removed, which decreases the final conversion rate to as low as 10%, while increasing recovery and purification costs. However, the Kneader Reactors are able to operate solvent-free or solvent-lean, even with highly concentrated masses. As a result, end polymer conversion rates range from 90 to 99%. The polymer mass can also be directly devolatilized to 500 to 1,000 ppm or lower solvent content. The technology is also suitable for solvent-free living and free-radical polymerization.

By incorporating devolatilization into the Kneader Reactors, processors are able to increase residence times and significantly reduce shear, which helps maximize polymer quality and yield while minimizing residual volatiles and operating costs.

In addition, Safrit says LIST expects to make some announcements in the future regarding its devolatilization technology. "We expect to have two different processes; one for temperature-sensitive plastics, polymers and elastomers and one for non-sensitive." He says the technology will use less water, and is a closed system, which allows all the solvents to be recovered. "Because it's a closed system that uses less water, it provides better environmental characteristics along with better product quality."

Philip Nising, director of polymer production technology with Sulzer (Winterthur, Switzerland; www.sulzer.com) agrees that improved devolatilization methods are needed, especially ones that reduce energy consumption. "This trend is growing in the rubber industry where there is a huge potential for energy savings, in particular in the concentration of the very dilute rubber/solvent solutions," he says. Rubbers, due to their very high viscosity and elastic behavior, are produced in a very dilute solution, typically containing around 90% low-boiling solvents. "Replacing steam stripping with dry processing, making use of Sulzer's static devolatilization technology in combination with dynamic mixers like extruders or kneaders, saves tremendous amounts of steam and thus, significantly reduces costs," he says.

Between 20 and 50% of the solvents can be removed using static flash technology developed by Sulzer, in which

Sulzer

FIGURE 2. The SMX plus static mixer is suitable for homogenization and dispersing tasks in laminar flow. Even challenging mixing applications, such as dosing a small amount of low-viscosity additive into a high-viscosity mainstream, can be performed efficiently

the solution is heated up in a heat exchanger equipped with Sulzer's static mixers and then flashed into a pressure-controlled devolatilization chamber under pressure, says Nising. The concentrated rubber solution can then be transferred into screw-type machines for final degassing. The Sulzer rubber pre-concentration technology helps save significant amounts of energy and reduce the required size of dynamic degassing machinery. It can also be used to revamp existing plants for rubber and other polymer-production plants.

Biopolymer growth

"Everyone is trying to get into the biopolymer industry while it's still new," notes LIST's Safrit. "The challenge here is that it is more difficult to produce these materials using traditional equipment because they don't have the same thermal characteristics."

Nising from Sulzer, agrees. "While some biopolymers can be used as true 'drop-in' products for existing polymers (for example, bio-polyethylene), most do actually have different properties than their oil-based predecessors," he says.

Polylactic acid (PLA) is a good example of this behavior. "Our PLA is not only seen as a simple drop-in material for polystyrene (PS) or polyethylene terephthalate (PET)," says Nising. "In fact, some of its properties are unique and give access to completely new product features. At the same time, due to the often different crystallization behavior, thermal stability or potentially acid degradation products, it might be necessary for processors to adapt or upgrade their equipment if they plan to switch product lines to PLA."

For this reason, Sulzer recently introduced a new generation of mixer-heat exchangers, particularly suitable for PLA production and other high-viscosity applications. The Sulzer SMX plus (Figure 2) and the Sulzer SMR mixer-heat exchangers (Figure 3) feature newly designed mixing elements. While the SMX plus exhibits a significantly lower pressure drop at similar mixing and dispersion performance, the SMR has an improved plug-flow behavior and is even less prone to wall effects than the first generation of SMR mixer-heat exchangers.

"Both products are components used in our PLA production technology. The Sulzer PLA process is a further development of known ring-opening polymerization processes for lactides," notes Nising. "With a significantly lower residence time, a higher productivity and much less racemization than conventional processes, our technology aims at the production of crystalline PLA grades for high-performance applications like fibers and injection molding."

Recycling plastics technology

"There's a huge interest in recycled product," says Greg Kimball, chief technology officer with Bepex (Minneapolis, Minn.; www.bepex.com). "Most of the work we're doing on the polyolefins and polyester side is in recycle, but there are a lot of challenges here associated with contaminants picked up during the recycle process, so we are working with processors to develop systems that can convert those recycled plastics into materials that can then be recycled back into food product containers and other applications."

Because Bepex's main focus is on the final treatment (which follows mechanical separation and size reduction, but comes before downstream processes like pelletizing or final product manufacture), much attention has been given to heating materials and gas contact to strip off the volatiles.

"The gas composition has to be tightly controlled, so along with the system, we developed a new gas system that enables us to produce a homogenous blend of gas with other volatiles that are required to produce the molecular weight and level of decontamination that's required," says Kimball.

What has resulted is Bepex's BePET Process (for the recycling of PET plastics; Figure 4), which consists of preheating of the washed recycled PET (RPET) flakes to temperature, integrated decontamination and solid state polymerization (SSP), a gas purification system, product cooling and product pack out.

The RPET flakes from the washing line are homogenized in a blending silo to create a uniform free distribution. The flakes are transferred to the top of the SSP train and are then fed by gravity into the BePET flake preheater. Here, the material is heated to reaction temperature by conduction from the hot multiple-disc rotor. The rotor also provides the required agitation and conveyance for efficient heat transfer and discharge. A portion of the nitrogen gas leaving the decontamination and SSP reactor sweeps the agitated bed surface and removes some dust, moisture and VOCs released during preheating. The heated flakes are discharged through an overflow weir to the reactor through a rotary valve. The balance of the gas leaving the reactor, along with the gas exiting the preheater is passed through a scrubber where the entrained fines and chemical contaminant are collected. The gas is dehumidified before being returned back to the inlet of the reactor.

The preheated flakes are discharged from the preheater into the reactor. The solids form a plug-flow, moving bed with sufficient residence time of four or more hours to remove the volatile contaminant within the RPET flakes and allow the system to control the product's intrinsic viscosity by the solid-phase polymerization reaction. Heated pure nitrogen with a low level of moisture and oxygen is fed through the bottom of the reactor, forming a counter-current flow to the downward moving bed of RPET flakes. The nitrogen removes any volatile contaminant residing the RPET

Sulzer

FIGURE 3. The Sulzer Mixer Reactor (SMR) is a tube-bundle heat exchanger that allows high-effective cooling or heating of viscous media. The SMR is a suitable choice to combine effective mixing with controlled heat transfer

flakes and byproducts of the SSP reaction out to the gas-purification system.

Following decontamination, the flakes are sent out via mechanical discharge to go through the flake cooling process and then onto their next destination.

"The modular component design of the system allows for easy integration with existing upstream and downstream operations," says Kimball. "A complete control system provides full automation for seamless flake processing and reduced labor costs. The system also provides continuous monitoring."

Improved controls

And, it's not just recycled plastics that demand tighter controls, according to Bill Barker, marketing manager with Littleford Day (Florence, Ky.; www.littleford.com). "Plastic and polymer processors' greatest challenges are keeping their costs low, maintaining the quality of their products and repeatability," he says. "In addition, they have to maintain high productivity to keep their costs low and reduce rework."

For this reason, Littleford Day is offering a lot of new and improved controls with their equipment so that processors can closely monitor every step of the process and maintain a history of each process.

"This not only gives them better control over the whole process, but

Bepex

FIGURE 4. The BePET process is said to be stable, efficient and reliable with no high-maintenance vacuum or extrusion decontamination required. The design promotes uniform plug flow and minimizes the potential for short-circuiting

also allows them to remotely monitor the process and provides a history that they can examine for trends when there is a problem or loss of productivity," explains Barker.

In addition, says Barker, providing multiple steps in one vessel also provides better control over the process and improves heat transfer to help shorten cycle times, tightening up the process and increasing throughput.

To help processors achieve all these goals, Littleford Day introduced the DVT Polyphase Reactor, which is a single apparatus designed to handle materials of varying composition, which may pass through phases from liquid to doughy, to granular, to powder, and has the combined operational features of pressure, vacuum and effective heat transfer.

The reactor operates according to the proven fluidized-bed mixing principle, whereby the materials being reacted are maintained in a mechanically fluidized suspended state, thus permitting the reacting mediums, gas-solid, or liquid-solid, to achieve intimate contact with each other and the heat-transfer surfaces. This results in a better-controlled reaction through effective heat transfer, improved reaction rates, increased efficiencies of reaction and the ability to complete the entire process in a single unit.

Turnkey systems

Many of the technologies discussed in this article are systems versus key pieces of equipment. Like most industries, plastic and polymer processors are losing their engineering staff due to budget cuts and downsizing, so they are asking technology providers to create turnkey systems for specific applications, says Safrit. "Processors are asking us to do it all," he says. "They want our reactor, vacuum system, condensation and pelletizing systems and then ask us to add controls and deliver it as a skid-mounted system that can be dropped in and started up. This requires us to take our technologies, put other know-how around it and provide a turnkey system."

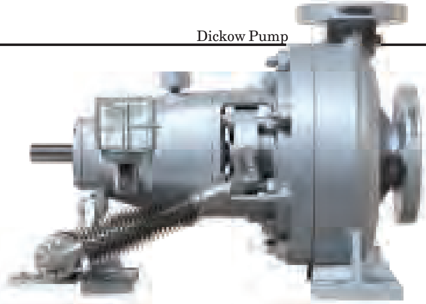
Nising agrees. "While Sulzer provided key equipment in the past, we have recognized and responded to the need for a complete solution around our components. For example we might provide gear pumps with our mixers or condensation systems for our devolatilization equipment," he says. "Concerning PLA and EPS technologies, we supply almost a complete turnkey plant. The customer still needs to plan and construct the building and utility systems, but Sulzer delivers preassembled plant modules around the key equipment, in combination with control systems and instrumentation."

The result, according to Safrit, is that some of these turnkey systems are allowing customers to improve their efficiency and reduce costs, as well as make new products. "This is opening the door to pharmaceutical polymers and biopolymers that were not previously cost-effective enough to make, as well as different polymers that haven't even been dreamed of," he says. ■

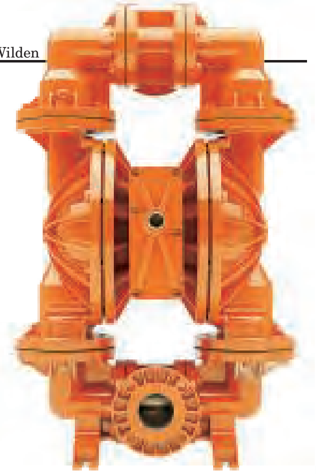
Joy LePree

FOCUS ON

Pumps



Dickow Pump



Wilden

Moyno

Blackmer

Neptune Chemical Pump

No cooling water needed for these hot-water pumps

This company offers a wide range of hot-water pumps for temperatures up to 530°F and design pressures up to 1,160 psi. Due to high vapor pressures, standard mechanical seals cannot be used for higher temperatures. Although cooled mechanical seals are the easiest solution, the required cooling water adds additional costs. An alternative is a standard mechanical seal with a pumping device and an external air cooler (photo). The cooler is a new development for this application. It needs no cooling water and is self-venting. — *Dickow Pump Co., Marietta, Ga.*
www.dickow.com

These pumps deliver non-pulsating, metered flow

The L-Frame Progressing Cavity Pumps (photo) are said to be ideal for handling clean, thin, shear-sensitive products to viscous, corrosive, abrasive slurries and sludges in many sectors of the chemical process industries (CPI). Standard flange models feature a modular design with a simple pin-type universal joint for easy maintenance. Open-throat models are also available. All models are available with a wide variety of drive options, sealing configurations, motors and controls. Other features include non-pulsating, metered flow; quiet, vibration-free operation; capacities to 450 gal/min and pressures to 2,100 psi; and handling entrained air and gases without vapor locking. — *Moyno, Inc., a unit of Robbins & Myers, Inc., Springfield, Ohio*
www.moyno.com

This sliding vane pump has 180-deg ports, and more

The NPH4F Sliding Vane Pump (photo) is a positive-displacement pump featuring 180-deg ports — a distinction from the 90-deg ports of its NP4F predecessor. Like the NP4F, the NPH4F has ductile-iron construction with an internal relief valve that protects against excessive pressures. Additional features include an optional cartridge mechanical seal, lip seal or triple-lip cartridge seal over the standard shaft packing; 4-in. weld, 4-in. ANSI 150# RF compatible or 4-in. NPT flanges. Options for jacketed heads are also available. The pump delivers maximum speeds of 500 rpm with differential pressures up to 200 psi. — *Blackmer, part of Pump Solutions Group, Grand Rapids, Mich.*
www.blackmer.com

Handle corrosives with these AODD pumps

Available in polypropylene (PP) and polyvinylidene fluoride (PVDF), the Advanced Series AODD (air-operated double-diaphragm) pumps (photo) are said to provide "superior" containment of dangerous chemicals (including acids, solvents and caustics) because the pumps do not have a mechanical seal or packing that can fail. The pumps also feature a bolted design and single-piece integral piston diaphragm, which eliminates a potential leak point. These ATEX-rated pumps also feature the Pro-Flo X Air Distribution System with Efficiency Management System, which allows the operator to dial in the actual operating parameters, regardless of the application demands or pump size. — *Wilden, part of Pump Solutions Group, Grand Terrace, Calif.*
www.wildenpump.com

A solar-powered injection pump for remote applications

The Solar D Series Chemical Injection Pump (photo) provides maximum containment, precise and consistent chemical-injection rates at pressures up to 1,200 psi (83 bars), and reduced field service and downtime. The accurate dosing rates (from 0 to 40 gal/d) translate into increased production with a corresponding reduction in chemical expenses. The unit is equipped with brushless motors; standard corrosion-resistant 316 stainless steel and PTFE chemical ends; hydraulically balanced diaphragm designed for reduced wear; and no dynamic seals for reduced leak points. — *Neptune Chemical Pump Co., North Wales, Pa.*
www.neptune1.com

Note: For more information, circle the 3-digit number on p. 64, or use the website designation.

Only two non-metallic parts contact fluid in this pump

The portable, non-metallic Flex-I-Liner rotary peristaltic pump (photo) evacuates drums and totes containing acids, caustics, salts, chlorides and reagent-grade chemicals, without corrosion of the pump or contamination of the fluid. The self-priming design has no seals to leak or valves to clog, and can run dry for extended periods without damage, says the company. Only two non-metallic parts contact fluid: a thermoplastic body block and an elastomeric flexible liner that can be replaced in the field without special tools. The pump is suitable for flows from 0.33 to 40 gal/min (1.25–151 L/h)


Vanton Pump & Equipment

Watson-Marlow Bredel Pumps

and pressures to 45 psig (310 kPa) at temperatures to 250°F (121°C). — *Vanton Pump & Equipment Corp., Hillside, N.J.*
www.vanton.com

This peristaltic pump handles sludge and slurry with ease

This hose pump (photo) reliably handles a variety of harsh materials, including abrasive sewage and slurry, making it suitable for the feeding of primary or thickened sewage to digesters or filter pressers. Advanced hose technology enables this pump to handle grit-filled sludge for extended periods of time. Peristaltic hose pumps are said to be virtually maintenance-free, with no seals to replace, no check valves to clog and no rotors and stators to wear out. — *Watson-Marlow Bredel Pumps, part of the Watson-Marlow Pump Groups, Wilmington, Mass.*
www.wmpg.com

Self-priming trash pump handles solids of up to three-inch size

TSC portable pumps (photo, p. 27) are a multi-purpose, automatic-priming trash-pump series that provides flows up to 1,460 gal/min and heads up to 15 ft. Available as 4- and 6-in. models, they handle solids with sizes up to 3 in. The pump end is self-priming, and capable of re-priming should the add-on automatic priming system fail. The pump case offers a large "clean out" that can be used to remove debris from the impeller or repair common wear components without having to disconnect the suc-


KNF Neuberger


Enerpac

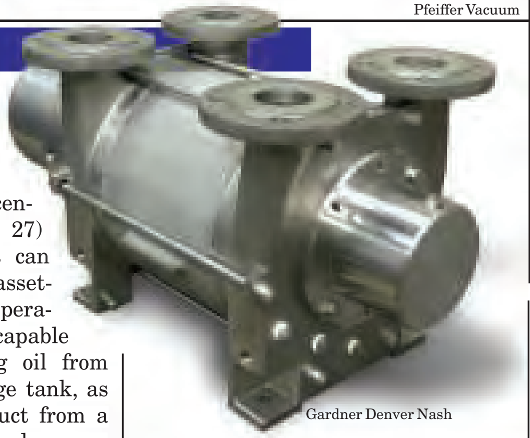

Griswold Pump


Thompson Pump

tion hose or pipe. — *Thompson Pump, Port Orange, Fla.*
www.thompsonpump.com

Consider this cordless hydraulic pump for remote applications
The new XC-Series cordless hydraulic pump (photo) delivers oil flow of 125 in.^{3}/min at its low-pressure setting, and 15 in.^{3}/min when operating at full pressure, up to 10,000 psi. The lithium-ion battery ensures the XC-Series pumps provide users with runtimes necessary to accommodate demanding application requirements. The pump offers the performance capabilities of an electric- or pneumatic-powered pump with the convenient portability of a hand pump, making it suitable for use in remote locations. — *Enerpac, Menomonee Falls, Wisc.*
www.enerpac.com

Metering pumps for precise, small dosing
The new FMM80 solenoid-driven diaphragm metering pump (photo) can be driven with single impulses to deliver discrete micro-volumes, or can be operated with a pulsed signal at a frequency up to 10 Hz to provide continuous flowrates up to 48 mL/min. With a long service life (more than 500 million strokes), the pump exhibits stability against varying pressure and sustains high repeatability over the pump's entire lifecycle. It also integrates a patented noise-suppression system for quiet-running operation and remains flow-tight in both directions with pressures of 14.5 psig at rest. The pump's diaphragm and patented valve system contributes to overall reliability and high performance, says the company. — *KNF Neuberger, Inc., Trenton, N.J.*
www.knfoem.com



Gardner Denver Nash

Pfeiffer Vacuum

Centrifugal pumps for LACT applications

The 811 Series ANSI centrifugal pumps (photo, p. 27) meet the challenges that can be associated with leased asset-custody transfer (LACT) operations because they are capable of completely transferring oil from a tanker to a user's storage tank, as well as transloading product from a tanker to a railcar, even under a variety of extreme operating conditions, says the company. These pumps have two times the wear area between the case and impeller, compared to closed-impeller designs. The casing of the 811 Series can be constructed of ductile iron, CDM4Cu, Alloy 20 or stainless steel. Pumps are available for flowrates to 4,000 gal/min with the ability to operate at temperatures up to 500°F. — *Griswold Pump Co., Grand Terrace, Calif.*
www.griswoldpump.com

An enhanced mag-drive pump covers a wide flowrate range

The 2BM1 magnetic drive pump Series (photo) is an enhancement to the 2BE1 Series, and is capable of achieving flowrates of 550–13,870 gal/min (125–3,150 m^3/h) and vacuum of 1 in. Hg, absolute (33 mbar, a). They can also be used as low-pressure compressors. Non-contact torque transmission is achieved via a permanent-magnet drive system. The 2BM1 pump is hermetically sealed, and certificates of compliance with all ATEX categories are available. — *Gardner Denver Nash, Charleroi, Pa.*
www.gdnash.com

A dry Roots pump slashes energy consumption in half

Introduced last month, the A 100 L ES dry multi-stage Roots pump (photo) is said to cut energy consumption by 50% compared to its predecessor, and its pumping speed is significantly higher in the low-pressure range. The fully integrated ES module reduces energy use to a minimum in the low-pressure range, which can lead to annual savings per pump up to 7,900 kWh, says the company. In addition to energy savings, the final pressure of the A 100 L ES is reduced to 7×10^{-4} mbar,

Quattroflow

which opens up new potential applications requiring an enhanced pumping capacity combined with low pressure. The noise level has also been reduced from 58 dB(A) to 55 dB(A). — *Pfeiffer Vacuum GmbH, Asslar, Germany*
www.pfeiffer-vacuum.com

Consider these pumps for high-purity, single-use systems

Quattroflow positive-displacement pumps (photo) are said to be ideal for single-use systems in biologics handling applications because they incorporate a four-piston diaphragm technology (with no mechanical seals) that is driven by an eccentric shaft and motor. The pumps are used in pharmaceutical and biotech industries in applications that require high containment, purity and cleanability, and are well known for transferring shear-sensitive media of aqueous solutions and biological products without damage. Four sizes are available covering capacities of 1 to 20,000 L/h. — *Quattroflow, a brand of Almatec Maschinenbau GmbH, Kamp-Linfort, Germany*
www.quatroflow.com

RO energy costs are slashed with this pressure controller

KSB

Scheduled for launch early this year is the Salino Pressure Center (photo), a compact unit for reverse osmosis (RO) seawater desalination. The Salino consists of an axial piston pump and an axial piston motor, arranged on a common shaft. Driven by the diaphragm return flow, the axial piston motor transfers its power directly to the pump shaft. This single unit performs three functions: creating high pressure, compensating pressure losses and recovering energy. No separate booster pump is required. Compared to conventional energy-recovery systems with pressure exchangers or Pelton turbines, the Salino design saves up to 50% in energy costs, says the manufacturer. The system is designed for RO systems with capacities up to 480 m^3/d. — *KSB AG, Frankenthal, Germany*
www.ksb.com ■

Gerald Ondrey

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FOCUS ON

Bins, silos and storage

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Lift and pour drums with this machine

The Pilot (photo) is a powered apparatus for lifting, rotating and dumping chemical-containing drums. The walk-behind drum handler has a floor-travel speed of 3.0 mph, a drum-lifting speed of 5 cm/s, and can dump drums up to 10.5 ft high and up to 11 in. beyond its straddle-type legs. The Pilot can handle drum weights up to 1,500 lb. The machine can maneuver with precision in tight areas, and lift and pour with high accuracy, the company says. — *Morse Manufacturing Co., East Syracuse, N.Y.*
www.morsedrum.com

This bulk-liquid shipping vessel is recyclable

The Flexitank (photo) is a multi-layer bladder designed to fit inside a standard, 20-ft ocean container, and can be used for shipping non-hazardous bulk liquids in the chemical and beverage sectors. Users can ship up to 31% more cargo than with intermediate bulk containers (IBCs) and drums. The Flexitank holds up to 24,000 L and is recyclable, which enables users to reduce shipping costs, because only one-way freight costs are required, says the company. Further, the recyclability allows users to avoid the cleaning required to avoid cross-contamination. — *DHL Global Forwarding, Bonn, Germany*
www.dhl.com

Handle corrosive chemicals with this storage system

This company offers what it calls a Special Product Package (photo) of its fluid storage-and-dispensing system. The special version is designed for applications involving corrosive chemicals and other abrasive fluids that require special handling for safety. The company's original storage system handles oils, lubricants and industrial fluids, and offers an alternative to 55-gal drums that the company says is safer, cleaner and more cost-efficient. The Special Product version has a glass sight gage in place of the standard PVC sight gage, and flexible steel hose underneath the tank in place of PVC hose. — *The IFH Group, Rock Falls, Ill.*
www.ifhgroup.com

Eliminate vapors inside chemical storage cabinets

The Vent-Box ductless filtration system (photo) is designed to protect personnel from chemical vapors found inside standalone chemical storage cabinets. The Vent-Box is equipped with this company's multiplex filtration system, which includes both a pre-filter and main filter that adsorbs, neutralizes or traps the target chemicals or particulate matter. At the same time, constant negative pressure removes vapors and particulate matter from the interior of the storage cabinet. Fumes are pulled via a flexible hose connected to the cabinet, and clean, filtered air is returned to the laboratory, so external ducting is not necessary. The Vent-Box is available in a variety of configurations to match vapor and particulate requirements. — *Air Science USA, Fort Myers, Fla.*
www.airscience.com

These storage cabinets can be wall-mounted

TiltView bins (photo) offer a space-saving way to store supplies, and can be used on a benchtop, attached to steel rails or mounted on the wall. The cabinets are made of high-impact polystyrene and the bins are clear polystyrene. The cabinets are available with optional locking rods and dividers. All six sizes of TiltView bins can be used individually or configured

Note: For more information, circle the 3-digit number on p. 64, or use the website designation.


Akro-Mils

into systems using any of the three optional hanging accessories. — *Akro-Mils, Akron, Ohio*
www.akro-mils.com

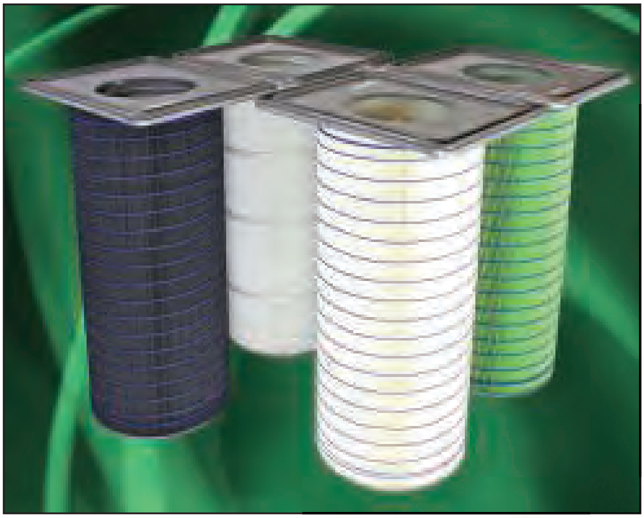
Dry bulk solids storage tanks that are made to order
BulkTec tank systems are designed to store dry bulk materials, such as food and grain products, chemicals, minerals and aggregates, plastics and others. Each tank is manufactured according to the requirements of the specific application. The tanks are coated with this company's proprietary coating process that provides maximum abrasion resistance and encourages smooth material flow. — *CST Industries Inc., Lenexa, Kan.*
www.cstindustries.com

Minimize product hang-up with these dry material silos
Storage silos for dry bulk materials from this company are available with the company's "smoothwall" steel sidewall panels. The smoothwall panels are heavier than light-gauge corrugated panels and minimize product hang-up with materials such as crushed rock dust, kiln dust, wood, coal and grains and seeds. The tanks are available in both welded and bolted versions in sizes up to 25,000 m^3. They come with abrasion-resistant coatings that are factory-applied and baked, as well as a host of gasketing and accompanying hardware options. — *Foremost Machine Builders Inc., Fairfield, N.J.*
www.foremostmachine.com

These storage cabinets have thicker doors
PIG Flammable Safety Cabinets have 14-gauge steel doors that are 56% thicker than alternative cabinets, according to the company. Also, the cabinets are equipped with a three-point zinc latch for non-sparking door closure, and a recessed handle design that won't catch on passing traffic. Available in a number of sizes and sump capabilities, PIG Safety Cabinets meet NFPA and OSHA specifications. They feature a leakproof sump to contain leaks drips and spills, as well as flame-arrestor vents to help prevent flashback ignition. — *New Pig Corp., Tipton, Pa.*
www.newpig.com ■

Scott Jenkins

MARCH New Products



Camfil Farr APC

Mettler Toledo

ASCO Numatics

These filters resist pulse cleaning

The HemiPleat eXtreme nano-fiber filter (photo) offers higher filtration efficiencies, greater durability and better resistance to pulse cleaning than competitive products, the company says. The standard HemiPleat filter delivers MERV (minimum efficiency reporting value) 15 efficiency — higher than the MERV 10 and MERV 13 ratings of alternative nano-fiber products. The product is also available in a high-efficiency model that delivers a tested efficiency of 99.999% on 0.5-micron and larger products by weight, the company says. Its proprietary, tri-layered technology is used to apply two layers of fine-pored nanoscale fibers that act as a pre-filter to the base media, capturing most dust at the surface before it imbeds in the filter. The durable and thick HemiPleat technology is said to increase the filter's cleaning ability and allows the base material to have larger pore sizes than standard cellulose media. — *Camfil Farr APC, Torrance, Calif.*
www.farrapc.com

A UV disinfection system with longer lamp life

The Microdynamics Series OCS721 (photo) is a microwave-powered, open-channel ultraviolet (UV) system for water disinfection in municipal wastewater and water reuse applications. The device uses microwaves to energize low-pressure, high-output, electrodeless lamps to generate a UV wavelength output of 254 nm, according to the company, an optimal wavelength for bacterial disinfection. The product offers operating-cost savings, the company says, with lower whole-life cost and longer UV lamp life. The system is validated for water reuse by the National Water Research Institute, and features a flow-pacing technology that can match UV dose. Since microwave-powered lamps are electrode-less, they remove a major failure mechanism found in traditional UV lamp technology, the company adds. — *Severn Trent Services, Fort Washington, Pa.*
www.serverntrentservices.com

A weigh module that handles up to 100 tons

This new PinMount weigh module (photo) offers manufacturers a chance to convert large tanks, vessels and silos into high-capacity scales, even in harsh environments and classified hazardous areas. The PinMount weigh-module family of instruments weigh from 7.5 to 100 tons. Easily integrated into existing structures, the module also provides SafeLock safety features that make installation foolproof. The PinMount's dual anti-lift devices and vertical downstops prevent damage due to environmental and component failure. — *Mettler Toledo, Columbus, Ohio*
www.mt.com

Direct-acting solenoid valves for use in harsh environments

Introduced last month, these two intrinsically safe solenoid valves (photo) have Ex ia IIC T6 certification. The solenoid operators are designed for use on the 327 range of direct-operated

solenoid valves, and are available in epoxy-coated aluminum or stainless steel. The solenoids are certified to ATEX, Category 1G/2D and Equipment Protection Level (EPL) Ga/Db. Both operators are IEC Ex approved and certified to IEC 61508 Functional Safety (SIL 3 capable). The 327 Series feature a brass, stainless-steel or aluminum body, and have a large flowrate (K_v = 0.45 m^3/h), operate from 0 to 10 bars and require no minimum operating pressure. — *ASCO Numatics Ltd., Skelmersdale, U.K.*
www.asconumatics.co.uk

GEA Refrigeration Technologies

Freeze food faster with this new impingement freezer

The HVF-Freezer (high-velocity freezer; photo) is said to be an improved freezer concept based on existing impingement-freezer technology. The new HVF uses high-velocity air jets to quickly reduce the outer layer temperature of food by breaking the insulating boundary layer, allowing the surface to be frozen very quickly. This effect allows the product to freeze faster than in conventional freezers and thus minimizing dehydration losses, says the company. For food processors, the benefits include: less cellular damage, thus better product quality; improved capacity (more than 10–15% over existing impingement freezers); higher yield; longer shelf life for foods; and faster freezing time, says the company. — *GEA Refrigeration Technologies GmbH, Bochum, Germany*
www.gea.com

Schubert & Salzer Control Systems

Valve position indicators that tell more than just on or off

The 2040 digital position indicator (photo) uses a colored light signal, visible from a distance, to show the open or closed position of a valve. Four different color signals are used: open and closed by yellow and green. At the push of a button, these colored signals can represent the end stops. In addition, when the end stop is reached, the digital position indicator outputs this as a switching signal to the contacts on the connector plug. The position indicator also signals maintenance information and issues error messages, which can be: stuck valve, wear in seals, temperature outside the permissible range and supply voltage too low. — *Schubert & Salzer Control Systems GmbH, Ingolstadt, Germany*
www.schubert-salzer.com

Witt-Gasetechnik

A new alarm module for gas mixers

The NXT+ (photo) is a new alarm module that monitors the gas pressures at the inlets of the gas mixer and in the mixing gas vessel to ensure a constant process quality. These mixers work with a high pressure-fluctuation tolerance and provide precise gas mixtures even at different input pressures. In the event of an irregularity, the alarm module protects against unwanted gas mixtures to avoid expensive production failures. By monitoring both the input pressure and that inside the vessel, the entire mixing process remains under control, says the company. — *Witt-Gasetechnik GmbH & Co. KG, Witten, Germany*
www.wittgas.com

Presto Lifts

Load pallets and lower injury risk with this machine

The new P3 All-Around level loader (photo) is designed to keep pallets at a convenient height for loading and unloading. The P3 has a pneumatic

Linn High Therm

airbag that automatically raises and lowers pallet as material is added or removed. It also features a turntable ring or platform to allow users to remain in the same spot while loading or unloading. Requiring no electrical power, the P3 can accommodate loads from 400 to 4,500 lb, depending on the spring package chosen, and can be moved easily with a forklift. — *Presto Lifts Inc., Attleboro, Mass.*
www.prestolifts.com

A furnace system for processing carbon fibers

The carbon-fiber pilot line (photo) consists of an oxidation furnace, carbonization furnace and a graphitization furnace, The four-zone oxidation furnace operates at 325°C for stabilizing precursor fibers, and has a connecting two-step system for carbonization and graphitization at the required temperatures (low temperature up to 1,050°C, high temperature up to 1,600°C, or 1,800–2,000°C optional) and dwell times. The necessary gas supply is in between. — *Linn High Therm GmbH, Eschenfelden, Germany*
www.linn.de

New coolant connections for high-flowrate applications

Coolant circuits must dissipate heat from applications such as welding or power-electronics installations.

This requires high flowrates within a compact space. This company has extended its Liquidline by designing two energy-optimized coolant connections (photo) that exceed the flowrates of previous Liquidline connections by an additional 15%. In addition to the existing 45- and 90-deg angle connections, the company now offers a connection in which the threads are connected to the release by means of a 45- or 90-deg angle piece made of copper. — *Eisele Pheumatics GmbH & Co. KG, Waiblingen, Germany*
www.eisele.eu


Eisele Pheumatics


Flexicon

This system fills boxes, bags and drums

The Multipurpose Filler (photo) dispenses bulk solid materials into boxes, drums and bulk bags by weight. The unit features a fill head that seals dust-tight against the inlet spout of bulk bags, or connects to transition adapters that seal against open boxes or drums. The filler uses the company's patented Twin-Centerpost frame, which is said to maximize strength and improve accessibility to the fill head, while simplifying construction and reducing operating costs. — *Flexicon (Europe) Ltd., Kent, U.K.*
www.flexicon.co.uk

A portable device that tests for fuel fraud

Nemesis is said to be the only analyzer of its kind — the first fully portable system to test for tampering in fuel. The device provides rapid sample analysis with marker detection down to extremely low levels. Results are available at the touch of a button and presented in a clear and precise quantitative format that eliminates the risk of ambiguous interpretation. Collected data can be transmitted using 3G or 4G technology to a central control. — *Tracerco Ltd., London, U.K.*
www.tracerco.com ■

Gerald Ondrey and Scott Jenkins

CHEMICAL ENGINEERING
FACTS AT YOUR FINGERTIPS
Department Editor: Scott Jenkins

Thermowell Installation

Temperature is among the most critical measurements in the chemical process industries (CPI) for operating safe and efficient processes. Because even a small error in temperature can lead to expensive consequences, accurate and reliable monitoring of temperature is required.

Thermowells

The most accurate temperature measurements occur when the sensor is in direct contact with the process fluid being measured. Since fluids in the CPI can often be corrosive or erosive, and can destroy a bare sensor quickly, the most common way of making temperature measurements is to use a thermowell. A thermowell is a hollow tube, often tapered, that projects into the process fluid to protect an immersed sensor. Because it is immersed in the fluid, the thermowell reaches the same temperature as the fluid.

Once a thermowell is installed, an immersion probe containing a temperature sensor is inserted into the thermowell from the outside so that the sensor fits flush against the end of the thermowell. Because the thermowell is immersed in the process fluid, it transfers the temperature of the fluid to the sensor. Thermowells can also be mounted onto the side of a tank.

Installing thermowells

The following are some general guidelines and tips for installing thermowells:

Material of construction. A thermowell's material of construction should be determined largely by the characteristics of the process fluid that flows past the thermowell, especially with regard to its corrosion properties, as well as its mechanical strength. The temperature and pressure ratings of all thermowells should be considered carefully when selecting to meet process demands. Common materials for thermowells include various grades of stainless steel, chrome-molybdenum steel, silicone bronze, Monel, Hastelloy B and C, nickel, titanium and others.

Type of connection. Thermowells are available generally with three types of connections — threaded, flanged and socket-welded.

Length of insertion. For best-possible accuracy, thermowells should be inserted into the pipe or vessel such that the entire temperature-sensitive part of the measuring element is projected into the medium being measured. For liquid measurement, the thermowell should allow the element to project into the medium at least one inch past the length of its temperature-sensitive area. For gases, the thermowell should allow the element to be immersed three or more inches beyond its sensitive length.

Bore size. For processes that are likely to use multiple types of temperature-measuring devices, the selection of a standard-sized bore diameter will allow the necessary flexibility.

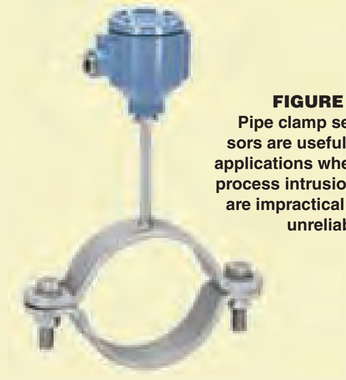


FIGURE 2. Pipe clamp sensors are useful in applications where process intrusions are impractical or unreliable

Tapered or straight. Thermowells are available with either straight walls or a tapered shape. Tapered-shank wells can provide greater stiffness with the same sensitivity compared to straight-shank thermowells. Tapered wells have a higher strength-to-weight than straight ones, which gives rise to a higher natural frequency. This can come into play when considering the vibrational effects experienced by the process. Fluid flowing around a thermowell forms a turbulent wake that has a definite frequency based on the diameter of the thermowell. Any thermowell should have enough stiffness to ensure that the wake frequency never equals the natural frequency of the thermowell itself. If the two frequencies match, the thermowell could vibrate enough to break off inside a pipe.

Further tips

- Thermowells can be used with pipes larger than 1.25-in. dia. In small pipe sizes, be sure the thermowell does not become an obstruction to flow
- Install the thermowell three to five pipe diameters away from elbows, flowmeters or other devices
- Follow the thermowell manufacturer's recommendations on pressure, temperature and fluid velocity. Thermowells can fail under certain conditions, including when under stress from wake-vortex-induced forces. These shedding vortices can lead to excessive vibration and potentially catastrophic failure when the vortex frequency approaches the thermowell's natural frequency (Figure 1)
- Incorrectly designed and installed thermowells may fail at high flowrates. Once the wake vortex-induced force (at frequency f_w) approaches the thermowell's natural frequency (f_n), catastrophic failure can occur unless correct thermowell calculations are performed
- For partially filled pipes, ensure that the bottom of the thermowell extends sufficiently into the process fluid
- For sizing and selecting thermowells, the American Society of Mechanical Engineers (ASME) Performance Test Code (PTC) 19.3 can be helpful. ASME PTC 19.3, which was rewritten in 2010, is a thermowell stress calculation that provides a mathematical indication that the material of construction and mechanical design of the thermowell will withstand the process conditions

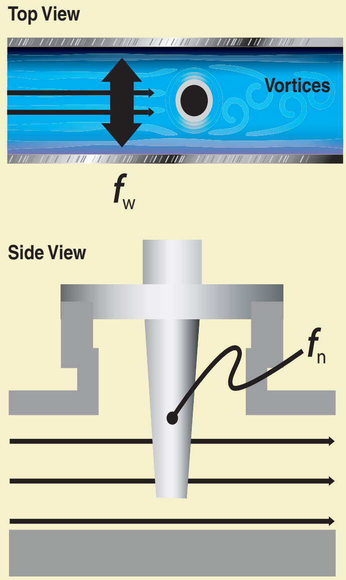


FIGURE 1. Incorrectly designed and installed thermowells may fail at high flowrates. Once the wake vortex-induced force (at frequency f_w) approaches the thermowell's natural frequency (f_n) catastrophic failure can occur unless correct thermowell calculations are performed

Immersed versus non-intrusive

In situations where thermowells are not feasible, engineers must consider non-intrusive temperature measurements (Figure 2).

While non-intrusive measurements are relatively easier to make than with a thermowell, and the apparatus is less expensive, surface measurements are not as accurate as immersion methods. Generally a surface measurement is accurate to within 1%, while immersion measurements can be accurate to within 0.1%.

Surface-based temperature-measurement devices should be insulated from the ambient temperature by wrapping the sensor connection and pipe with insulation. This helps avoid potentially false measurements.

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2. Nguyen, K., Applying CPI Temperature Sensors, *Chem. Eng.*, Sept. 2010, pp. 28–31.


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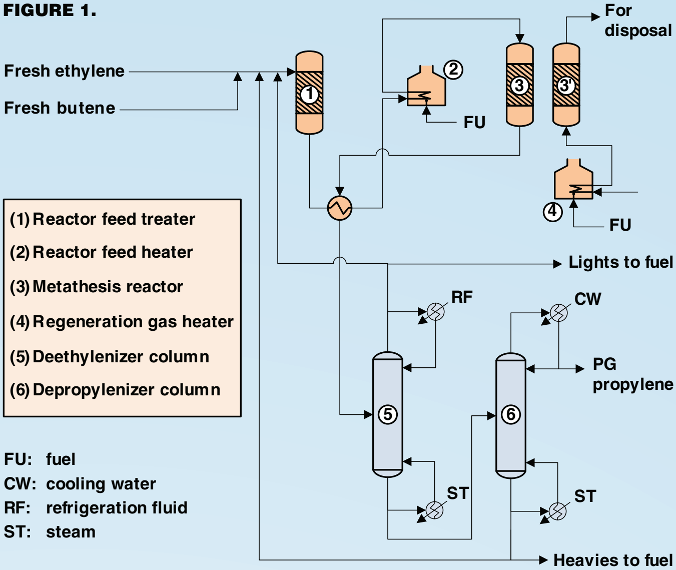
Propylene Production via Metathesis

By Intratec Solutions

Propylene is typically considered a co-product in steam crackers and fluid-catalytic-cracking (FCC) processes, which are primarily driven by ethylene and motor gasoline production, respectively.

Recently, most U.S. ethylene producers have shifted to lighter feedstocks due to the availability of low-cost natural gas and natural-gas liquids (NGLs) from shale. This shift drastically decreases propylene byproduct output. Since propylene demand is growing faster than that of ethylene, and is expected to continue increasing, a gap between propylene supply and demand is arising. This brings about the possibility of establishing chemical processes for on-purpose propylene production, and one of the processes depends on metathesis chemistry.

FIGURE 1.



The metathesis process

Metathesis, also known as disproportionation, is a reversible reaction between ethylene and butenes in which carbon-carbon double bonds are broken and then rearranged to form propylene. Both ethylene and 2-butenes are mainly supplied from steam-cracker units, but can also be obtained from FCC units. The metathesis process depicted in Figure 1 is similar to the OCT (olefins conversion technology) process developed by Lummus Technology (part of Chicago Bridge & Iron Co. N.V.; the Hague, The Netherlands; www.cbi.com) and makes use of a tungsten oxide catalyst, along with a magnesium oxide co-catalyst. The OCT process typically achieves a propylene yield of about 90%.

The process is divided into two main areas: purification and reaction; and separation.

Purification and reaction section. Fresh and recycled ethylene and butene are mixed and fed to treatment equipment that removes potential catalyst poisons, such as oxygenates and sulfur. After treatment, the stream is vaporized and heated to the reaction temperature, between 280 and 320°C. The metathesis reaction occurs in a fixed-bed catalytic reactor, and butene is commonly employed in excess to minimize eventual side reactions that produce mostly five- to eight-carbon olefins. Coke, another byproduct of the reaction, is deposited on the catalyst throughout the process. Each reactor can run for about 30 days before requiring regeneration, where coke is burned off in a controlled atmosphere.

Separation section. Propylene purification is carried out in two columns. The stream leaving the reactor is cooled and sent to the deethylenizer column, the overhead stream is recycled back to the reactor and the bottom stream is fed to the depropylenizer column, which produces polymer-grade propylene in the overhead, as well as a heavies product stream (four-carbon compounds and greater) that is also recycled.

Economic performance

An economic evaluation of the process was conducted for three distinct locations — the U.S. Gulf Coast region, Germany and Brazil — and is based on data from the third quarter of 2011. The following assumptions were taken into consideration:

- A 350,000 ton/yr metathesis unit erected inside a petrochemical complex (all equipment is represented in the simplified flowsheet in Figure 1)
- Storage cost of the main product is equal to 20 days of operation, and storage cost for feedstocks was not considered
- The excess fuel gas generated in the process is considered to be sold to a nearby chemical plant at natural gas prices

The estimated capital investment (including total fixed investment, other capital expenses and working capital) and for such a plant on the U.S. Gulf Coast is about $245 million, the lowest among the regions compared. Germany presented a higher capital investment — $295 million — but the lowest operating cost, at about $1,320/ton, compared to $1,480/ton in the U.S. In Brazil, both the initial capital investment for a metathesis plant and the operating costs were the highest.

Global perspective

Despite the higher operating costs, metathesis plants in the U.S. have exhibited the highest EBITDA (earnings before interest, taxes, depreciation and amortization) margins, since the propylene product prices in North America were higher than those in Europe.

The higher EBITDA, coupled with the lowest total capital investment, makes the U.S. the most promising region for new metathesis projects. However, the current number of metathesis units worldwide shows that such units can also be profitable outside the U.S., as shown in the world map (Figure 2). ■

Edited by Scott Jenkins

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FIGURE 2. Each mark in the map corresponds to an existing metathesis plant. The nominal capacity of each plant follows the legend below:

Dave Johnson, ChemTreat

Beware of Flow-Accelerated Corrosion

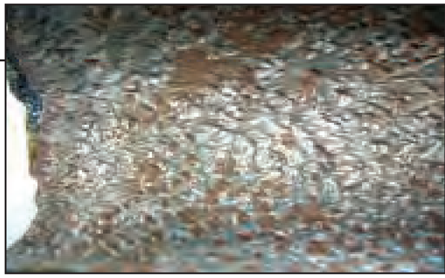

FIGURE 1. Single-phase FAC shows a distinctive orange-peel texture on the pipe surface

Operators of steam-generating systems should understand flow-accelerated corrosion and the potential problems it can cause

Dave Johnson, ChemTreat

FIGURE 2. Tubewall thinning is caused by single-phase FAC

Brad Buecker
Kiewit Engineering Group

Many chemical process industries (CPI) facilities utilize high-pressure steam generators to produce both electricity and process steam. This technique is commonly known as combined heat and power (CHP). A popular approach in recent years has been to select a combined-cycle power and steam-generation unit to utilize the combination of a combustion turbine and a heat-recovery steam generator (HRSG) for process-steam generation and perhaps additional power generation. Owners and operators of these combined-cycle units, as well as other steam generators, need to be aware of the phenomenon known as flow-accelerate corrosion (FAC), which, if ignored, can lead to corrosion-induced failures of steam systems.

Dissolved oxygen treatment

Three decades ago, at the beginning of the author's career in the utility industry, conventional wisdom said that any dissolved oxygen that entered the condensate and feedwater system of a high-pressure steam generator was harmful. At that time, over 50% of the power produced in the U.S. came from coal. Coal-fired steam-generation units typically have complex condensate/feedwater networks with numerous feedwater heaters. The prevalent thinking at the time was that any trace of dissolved oxygen (DO) would cause corrosion. And indeed, dissolved oxygen can be very problematic in uncontrolled environments. Therefore, virtually all feedwater systems for high-pressure steam generators were equipped with a deaerator for dissolved gas removal. A properly operating deaerator can lower DO concentrations to 7 parts per billion (ppb).

However, even this residual DO concentration was still considered harmful, so chemical deaeration was also the convention at most plants. The workhorse for chemical deaeration was hydrazine (N_2H_4), a reducing agent that reacts with oxygen according to the following reaction:

$$N_2H_4 + O_2 \rightarrow 2H_2O + N_2(g) \quad (1)$$

Hydrazine proved advantageous because it does not add any dissolved solids to the feedwater, it reacts with oxygen in a one-to-one weight ratio, and it is supplied in liquid form in solutions with concentrations of 35%. Also, a primary benefit of hydrazine is that it will passivate oxidized areas of piping and tube materials as follows:

$$N_2H_4 + 6Fe_2O_3 \rightarrow 4Fe_3O_4 + N_2(g) + 2H_2O \quad (2)$$

$$N_2H_4 + 4CuO \rightarrow 2Cu_2O + N_2(g) + 2H_2O \quad (3)$$

Hydrazine residuals were typically maintained at relatively low levels of perhaps 20 to 100 ppb. Oxygen scavenger treatment was coupled with a feed of ammonia or an amine to maintain feedwater pH within a mildly alkaline range — 8.8 to 9.1 for mixed-metallurgy feedwater systems and slightly higher for all-ferrous systems.

$$NH_3 + H_2O \rightarrow NH_4^+ + OH^- \quad (4)$$

This program became known as all-volatile treatment [AVT(R)].

Due to the suspected carcinogenic nature of hydrazine, alternative chemicals, such as carbohydrazide, methyl ethyl ketoxime and others gained popularity, but the intent remained the same — to establish a reducing environment in the feedwater circuit, thus inhibiting oxidation of metal. The AVT technique became a standard in the industry.

A condensate-system failure on Dec. 9, 1986 changed the situation. A pipe elbow in the condensate system of the Surry Nuclear Power Station (near Rushmere, Va.) ruptured, and the failure caused four fatalities and tens of millions of dollars in repair costs and lost revenues [*1*]. As a result of this accident and others similar to it, researchers learned that the reducing environment produced by the oxygen-scavenger feed results in single-phase FAC.

The corrosive attack occurs at flow disturbances, such as elbows in feedwater piping, and economizers, feedwater-heater drains, locations down-

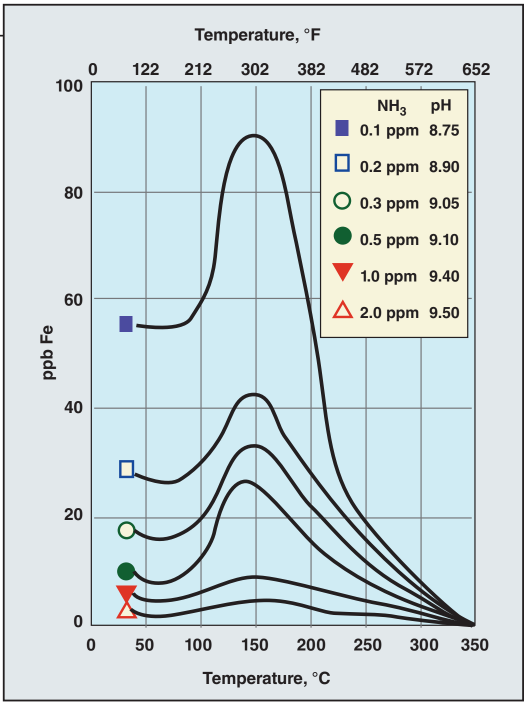

FIGURE 3. The dissolution of the carbon-steel matrix is a function of pH and temperature [*1*]

stream of valves and reducing fittings, attemperator piping, and, most notably for the combined-cycle industry, in low-pressure evaporators.

Single-phase FAC

The chemistry of single-phase FAC and its potentially catastrophic effects are outlined here. With single-phase FAC, wall-thinning occurs gradually until the remaining material at the affected location can no longer withstand the process pressure, whereupon catastrophic failure occurs.

When a steam generator is placed into service, carbon-steel feedwater piping and waterwall tubes form a layer of protective iron oxide known as magnetite (Fe_3O_4). Magnetite is actually a composition of FeO (with iron in a +2 oxidation state) and Fe_2O_3 (with iron in a +3 oxidation state).

The combination of a reducing environment (caused by the oxygen scavenging species) and localized fluid-flow disturbances causes the dissolution of ferrous ions (Fe^{+2}) from the metal and from the metal-oxide matrix. Well known data from the Electric Power Research Institute (EPRI; Palo Alto, Calif.; www.epri.com) show that iron dissolution is greatly influenced by not only reducing conditions, but also by solution pH and temperature.

As Figure 3 illustrates, corrosion reaches a maximum at 300°F. Thus, feedwater systems and HRSG low-pressure evaporators are particularly susceptible locations. Also note the influence of pH — as reflected by ammonia concentration — on the corrosion characteristics. This factor becomes quite important with regard to controlling FAC.

In large measure, coal-plant personnel have recognized the problem of single-phase FAC, and have adopted alternative feedwater-treatment methods to mitigate the issue. Elsewhere however, such as in CHP projects within the CPI, proposals for combined-cycle steam and power units often specify an oxygen-scavenger feed system.

Solutions to single-phase FAC

HRSGs, by their nature, typically have many waterwall tubes with short-radius elbows. Thus, the HRSG unit contains many locations where single-phase FAC could be a concern. A primary method to mitigate this attack is to select the proper feedwater treatment scheme.

Approximately 40 years ago, researchers and chemists in Germany and Russia began using a program known as oxygenated treatment (OT) to minimize carbon-steel corrosion and iron dissolution in supercritical steam generators. The key component of the program was, and still is, deliberate injection of pure oxygen into the condensate/feedwater network to establish oxygen residuals of up to 300 ppb. What chemists discovered is that in very pure feedwater (cation conductivity ≤ 0.15 µS/cm (microsiemens per cm), the oxygen will intersperse and overlay magnetite to generate a tenacious and very insoluble film of ferric oxide hydrate (FeOOH). The OT approach typically lowered feedwater iron concentrations to 1 ppb or less, and, as researchers have subsequently confirmed, greatly minimized single-phase FAC. Currently, OT is the preferred feedwater treatment for most once-through utility steam generators around the world. In the U.S., an oxygen residual range of 30 to 150 ppb is common, with a recommended pH range of between 8.0 and 8.5. OT has been applied to a few drum units, where EPRI guidelines call for a feedwater pH range of 9.0 to 9.4, with a dissolved oxygen concentration of 30 to 50 ppb.[*1*]

Although OT has been successfully applied to drum boilers, another program has evolved that is very popular for condensate/feedwater in these steam generators. It is known as all-volatile treatment, oxygen [AVT(O)]. With AVT(O), oxygen is not deliberately injected into the condensate, but rather the amount that enters from condenser air in-leakage, according to "normal" conditions (we will examine "normal" conditions shortly) is allowed to remain without any oxygen-scavenger or metal-passivator treatment. It should be noted at this point that neither OT nor AVT(O) are permissible for feedwater systems containing copper alloys, as the oxygen would simply be too corrosive to the metal. The following text therefore focuses upon AVT(O) for all-ferrous systems.

When researchers developed AVT(O), they took into account the pH effect on carbon-steel dissolution, as previously illustrated in Figure 3. AVT(O) guidelines evolved to the following parameters:

- Recommended pH range: 9.2–9.6
- Feedwater dissolved oxygen concentration: ≤10 ppb

As with OT, the condensate must be quite pure to allow oxygen to generate the FeOOH protective layer rather than cause pitting. However, the cation-conductivity upper limit with AVT(O) is a bit more relaxed at ≤ 0.2 µS/cm.

A relatively new twist has emerged regarding AVT(O) philosophy. Chemists have discovered that the heretofore established limit of 10 ppb DO in the feedwater may allow single-phase FAC at some isolated locations in feedwater systems where eddy effects appear to prevent the dissolved oxygen from reaching the metal surface. It is the author's understanding that guidelines may be modified to raise the upper DO limit to 20 ppb.

The amount of air in-leakage that establishes the "normal" condition of 10-ppb dissolved oxygen in the condensate is not a hard and fast value. The old rule of thumb for proper condenser conditions is a limit of 1 scfm (standard cubic feet per minute) of air in-leakage per 100 MW of capacity.

However, the author has worked with units in which the air in-leakage ratio was significantly higher, but where the condenser vacuum pumps had sufficient capacity to remove the gases. Quite often, a failure at the condenser shell or within auxiliary equipment may cause a sudden spike in dissolved oxygen concentration. As contrasted to pure oxygen feed, such as with OT, air in-leakage also allows carbon dioxide to be drawn into the condensate, which raises the conductivity. In such cases, plant personnel need to search for the leak or leaks and repair them promptly. Much more problematic is a condenser tube leak, which not only raises the condensate dissolved solids concentration, but introduces impurities to the steam generator. These effects can be quite dramatic [2].

Chemical and material select

Elevated pH also has a beneficial effect in mitigating FAC. Thus, the guidelines for feedwater pH now recommend a range of 9.2 to 9.6. With EPRI's phosphate continuum program or with caustic treatment alone, the drum pH can be controlled within a range of 9 to 10 quite readily.

A complication sometimes arises with HRSGs. Most HRSGs are of the multipressure, drum, vertical tube style. In some cases, the feedwater circuit is designed such that the feedwater enters each pressure circuit separately. In many others, however, the entire feedwater stream is routed to the low-pressure (LP) evaporator for additional heating before being distributed to the intermediate-pressure (IP) and high-pressure (HP) steam generators. In these situations, phosphate or caustic feed to the LP circuit is not permissible due to the downstream effects on attemperator (steam-temperature controller) chemistry, and IP and HP economizers. For these situations, the LP pH must be controlled via ammonia or amine injected into the feedwater. If the condenser uses tubes made from ferrous materials, the pH may be taken higher than the 9.2 to 9.6 range listed above without ill effects. However, copper-alloy tubes would suffer from extensive corrosion at the higher concentrations of ammonia.

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FIGURE 4. The effects of two-phase FAC are shown here in a deaerator

For new HRSGs, single-phase FAC control can also be addressed in large measure by materials selection. The addition of a small amount of chromium to FAC-susceptible spots virtually eliminates the corrosion. A primary example is LP waterwall elbows. Fabrication of the elbows from 1¼ or 2¼ chrome alloy can provide great benefit. While this alloy addition adds some cost to the project, the materials are quite resistant to FAC.

Two-phase FAC

Many steam generators, regardless of type, are susceptible to two-phase FAC. As the name implies, this corrosion mechanism occurs where water flashes to steam, resulting in a mixed-phase fluid.

For conventional units, feedwater heater shells and heater drains are common locations for two-phase FAC, but this equipment is not common for HRSGs. However, de-aerators also experience two-phase fluid flow. As fluid flashes upon entering a de-aerator, oxygen departs with the steam. Thus, the water that impinges upon metal surfaces does not maintain an oxidizing environment. Also, the pH of entrained water droplets within the steam is usually lower than the bulk water pH. The combination of these factors often initiates FAC.

As has been noted, elevated pH will help to mitigate FAC, but the HRSG configuration dictates the maximum treatment allowed. If the LP system is utilized for heating of feedwater to the IP and HP circuits, solid alkali treatment (trisodium phosphate or caustic) of the LP circuit is not permissible. Control of pH can only be accomplished by ammonia, but it should be noted that ammonia hydrolysis, as previously outlined in Equation 4, decreases with increasing temperature. As with single-phase FAC, a method to combat two-phase FAC is fabrication of susceptible locations with chromium-containing steel.

This article outlines the primary issues behind the recommended non-use of oxygen scavengers in all-ferrous, high-pressure steam generators. Certainly for lower-pressure industrial and auxiliary boilers, treatment programs may be more flexible. Methods and programs to detect FAC in existing plants can be found in [*1*]. ■

Edited by Scott Jenkins

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Author

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Corrosion in Flexible Burner Hoses

FIGURE 1. A cutaway view shows the stainless-steel construction of core bellows tube with wire braid outside

Special care must be taken to avoid corrosion in flexible hoses for burners. This failure analysis illustrates the mechanism and provides recommendations

TABLE 1. SPECIFICATIONS OF FLEXIBLE HOSE AND BURNER TIP

	Material	Specification	Remarks
Flexible hose with AISI Type 304 wire braid	AISI Type 304	Size 0.5 in., 0.26-mm thickness, AISI Type 304 strip annularly corrugated tube	See Fig. 1
Burner tip	300 series stainless steel	Casting (1,800°F resistant)	See Fig. 2

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SK Innovation

Piping leakage due to corrosion has the potential to cause catastrophic fires and damage to process equipment in petroleum refining and other chemical process industries (CPI) facilities. When such incidents occur, a large amount of damage and a long downtime results. Despite the risks, mistakes are often repeated in the way burner piping is designed and used.

Using the failure-analysis investigation of a specific refinery fire to illustrate, this article describes the problem of corrosion-related leakage in flexible burner hoses, and provides recommendations on burner-piping design criteria. It also discusses remedial measures, as learned from the investigation, that can be taken to help avoid future accidents.

Flexible hoses in burner systems

Flexible hoses have several specific advantages when used in the design of pipe work. Among the advantages are the hoses' ability to absorb vibration and operate effectively under high pressure. However, the most important advantage to the present discussion is the ability of flexible hoses to be adjusted easily. When employed in burner piping for fuel oil, atomizing steam or fuel gas, flexible hoses are generally used for the purpose of burner-gun positional adjustment. Flexible hoses permit a more economical installation compared to rigid piping in difficult locations — when connected to flexible hose, it is relatively easy to adjust the elevation or orientation of a burner gun without any mechanical modifications in burner piping. Flexible hose for burner piping is common in the petrochemical industry, because it allows easy fit-up of burner piping during installation, and allows for the minor misalignment of components. Also, flexible hoses allow more convenient maintenance. Information on the size, thickness and flange characteristics of flexible hose are found within the design specification, ANSI LC1-2005, CSA 6.26-2006 (Fuel Gas Piping Systems Using Corrugated Stainless Steel Tubing).

Made from stainless-steel strips, the inside tube of a flexible hose is annularly corrugated tube manufactured by continuously processing the material on a high-speed, automatic-forming machine. The geometry of the corrugations gives the flexible metal hose excellent hoop strength, providing superior resistance to collapse when exposed to high pressure. After the initial processing, the flexible hose is annealed in a furnace without oxidation to completely eliminate residual stresses. The outer covering is made from a stainless-steel wire braid which provides the necessary protection from abrasion (Figure 1).

The burners in the cases descrbed here are combination oil- and gas-firing, which are designed to operate with both liquid and gas fuels. Fuel-gas burner tips (Figure 2) are made from high-temperature metal alloy casting, because they are typically exposed directly to the heat source (flame) in the radiant box of fired heaters. The burner components, including the burner tip, are designed in accordance with the minimum requirements as shown in API standard 560 (Fired Heaters for General Refinery Service).

The use of flexible hoses in burner systems also carries some limitations. Compared to rigid piping, flexible hoses (corrugated tube) are formed out of thin-walled tubing. One of the most serious drawbacks of flexible hose is that their thickness (0.26-mm) is not sufficient to withstand corrosion in cases where the hose is not completely chemically resistant to the media to which it will be exposed. Corrosion then becomes a serious concern, and engineers need to account for non-obvious sources of corrosive materials and various corrosion mechanisms.

Once corrosion is initiated, the life of corrugated flexible tube becomes very short. The use of corrosion-resistance charts published by manufacturers of piping components, such as pipe fittings, flanges and others, is not recom-

FIGURE 2. A new burner tip needs to have the proper size and orientation, as specified on the burner drawing

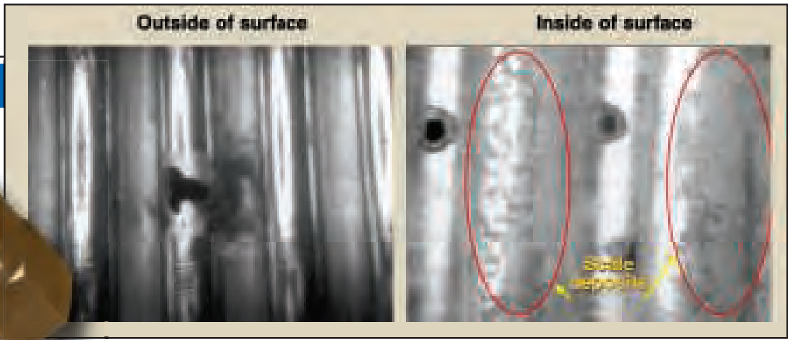

FIGURE 3. This failed flexible hose shows corrosion-induced pinholes

mended for flexible metal hose because these other "regular" piping components generally have much heavier wall thicknesses than corrugated metal hose, and therefore may have allowable corrosion rates that would be unacceptable for the flexible hose.

Regarding cost comparisons between flexible hose and rigid piping — especially for 1-in. burner piping — the price of stainless-steel flexible hose is about twice that of carbon-steel rigid piping. However, the installation cost of the rigid piping is about three times higher than what is required for flexible hose, since the rigid piping requires special fit-up and welding. So although flexible hose may seem economically advantageous at the installation stage, the longer-term costs of maintenance and safety must be taken into account, especially if there is a possibility of corrosion.

Piping leaks cause a fire

The following is an account of a fire around the burner piping at a petroleum refinery, and of the subsequent investigation and failure analysis that identified dew-point corrosion as the major factor in the pipe's failure and the resulting fire. The situation described here has parallels to other facilities using flexible hoses as burner piping.

During the start-up of a fired heater, right after a turnaround in a petroluem refinery, there was a severe fire around the burner piping that heavily damaged neighboring equipment and caused unscheduled downtime for a long period, mainly due to the fire damage of instrument cables. After putting out the fire, further investigation showed that the flexible hoses used for fuel gas were leaking. Similar to many refinery fires, the incident started with a single problem of piping leakage. Without an intermediate step, the pipe exploded and the fire spread to the rest of the main equipment, including the instrument cables.

FIGURE 4. Plugged tips will lead to unstable flames, flame impingement and pollution problems

The process details were as follows: operating fuel-gas pressure of 1.2–1.5 kg/cm^2; operating fuel-gas temperature of between 30–60°C; fuel-gas composition of 69% H_2, 10% ethane, 8% C_3H_8, and 13% other components, but no critical toxic components. The system was designed to operate with either oil or gas, but could not use both fuels simultaneously.

When investigators visually observed the flexible hose bellows (corrugated stainless-steel tube) for initial clues, they found many small pinholes, especially at the bottom section of the tube, as depicted in Figure 3. The pinholes are characteristic of pitting-type corrosion, where localized metal-thickness loss occurs, leaving pits. Detailed specifications of flexible hose and burner tips are described in Table 1. In addition to the pinholes on the bottom outside surface of the flexible tubes, other initial visual observations included the following:

- Liquid stagnation marks were noticed at the bottom of the corrugated tube
- Severe thinning and pitting were noticed at the bottom area on the internal surface of the corrugated tube
- The region near the pits, which is thinned due to corrosion, showed layers of deposits over the surface
- The failed portion of the tubes contained pitting holes, which had perforated the tube initiating from the inside surface. The perforation made holes approx. 1–2 mm that were surrounded by thin pits, as depicted in Figure 3
- The top part of the gas tip was melted out, and there was severe coke built-up inside of the gas tip as depicted in Figure 4
- Gas tip holes were melted, plugged and eroded

Regarding the melted fuel-gas tip and severely plugged gas-tip holes (Figure 4), investigators found that, upon reviewing the maintenance history, the fuel-gas burner tips had been frequently replaced during operation due to severe damage. In general, because burner tips are custom-designed in number, size and in the angle of the tip holes for specific applications (Figure 2), the damaged burner tip will result in undesired flame characteristics, including length and size, as well as low performance in operation, such as higher NOx emissions.

Failure analysis

Engineering failure analysis has two major objectives: to determine the failure mechanism and to determine the failure root cause. The failure mode is the basic material behavior that results in the failure, for example, pitting corrosion. The root cause is the fundamental condition or event that caused the failure, such as material defects, design problems and improper use. The present investigation of the failed flexible hoses considered several possible reasons for the tube failure. They include the following:

- The wrong material of construction was selected, or had an abnormal composition
- The flexible tube was installed improperly
- The corrugated flexible tube was damaged due to kinking or excessive bending
- A process upset occurred, where

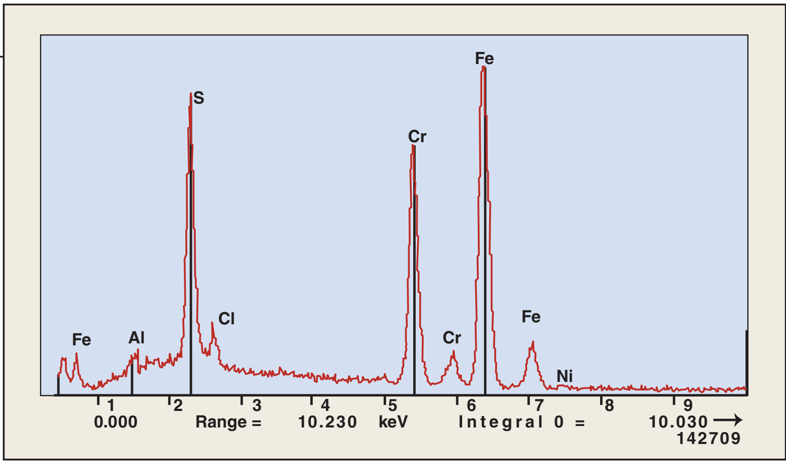

FIGURE 5. EDX analysis can help identify the chemical species in the deposits inside the failed tube

temperature or pressure were higher than the design conditions

- Corrosion due to a corrosive chemical species not related to the material of construction

The chemical composition of the corrugated tube was reviewed, and a metallurgical analysis conducted. The chemical analysis confirmed that the material of construction (MOC) of the flexible hose tube was Type 304 stainless steel, which is the correct MOC for the design fuel gas composition, and the failed tube satisfied the ASTM International specification for AISI Type 304 stainless steel. Also, no abnormalities were noticed in the tube metallurgy, so tube failure due to the wrong material of construction was ruled out. Similarly, there was no evidence of incorrect installation, such as kinking or twisting of the flexible hoses. In accordance with API RP535 (Burners for Fired Heaters in General Refinery Services), the flexible hoses were installed within their designed radius of curvature.

EDX and corrosion

Attention then turned to corrosion as ultimate cause of the accident. Because the corroded pits were found on the corrugate tube, it was necessary to carry out EDX (energy-dispersive X-ray spectroscopy) in an effort to identify the component of corrosion from the deposit scale on the inside of the tube. EDX is an analytical technique used for the elemental analysis or chemical characterization of a sample. The EDX studies were carried out to determine the elemental compositions of the matrix and the deposits and scales on the failed tubes. The EDX profile (Figure 5) of the failed tube shows iron, sulfur and chromium in very high concentrations. The results of EDX studies indicate that there was substantial incorporation of sulfur compounds in the corrugated tube inside during operation. Sulfur and chloride helped cause the corrosion, while Cr, Fe, Ni resulted from the corrosion. The pitting corrosion is caused by the effects of sulfur and chloride, especially when they are present in hydrous solutions. Attack on the material is affected by chemical concentration, temperature and the type of material from which the corrugated tube is manufactured.

Stagnation of fuel gas condensate during heater operation may increase the corrosivity of the environment, and reduce stability of the protective surface films and increase susceptibility to metal loss. Most stainless steels form a protective film of stable oxides on the surface when exposed to oxygen gas. The rate of oxidation is dependent on temperature. At ambient temperatures, a thin film of oxide is formed on the stainless steel surface. In accordance with the corrosion resistance charts published by NACE (National Association of Corrosion Engineers), it is not recommended for Type 304 to be used with sulfuric acid and sulfurous acid.

A number of key findings arose from the EDX analysis, including a relatively large amount of sulfur, despite the fact that the fuel gas contains virtually no sulfur at all. This implies that the main cause of the corrosion may not be related to the fuel gas itself. The sulfur content in fuel gas is only 10 ppm, so the fuel-gas condensate is not likely to have caused the corrosion. Tube failure due to fuel gas was ruled out.

Dew-point corrosion

Given the evidence of sulfur from the EDX, the question becomes, what is the source of the sulfur? In approaching the corrosion issue, we must look into the fluegas side, as well as fuel gas itself, to find the source of the sulfur. It is crucial to understand the mechanism of fluegas acid dew-point corrosion. It is very important not to cool the fluegas below its acid dew point because the resulting liquid acid condensed from the fluegas can cause serious corrosion problems for the equipment. During oil firing, the gas burner is not in operation, however the gas guns are placed in the burner and the gas tips are exposed to the hot fluegas in the radiant box. One of the most striking features of this combustion process is that the fluegas penetrates through the idling fuel-gas tip holes, and collects inside of the corrugated tube.

To explain the fluegas flow mechanism, and why fluegas enters the burner gun, it is helpful to use Charles' Law of gas volume — at constant pressure, the volume of a given mass of an ideal gas increases or decreases by the same factor as its temperature on the absolute temperature scale. The hot fluegas continuously flows into the burner gun and into the corrugated tube due to the gas-volume difference between the hot burner-tip area and cold flexible-hose area. Once the fluegas stays inside the corrugated tube, then the fluegas becomes condensate when the temperature drops below the dew point. The fuel oil contains sulfur at a concentration of 0.3 wt.%, and the combustion of fluegases may also contain small amounts of sulfur oxides in the form of gaseous sulfur dioxide (SO_2) and gaseous sulfur trioxide (SO_3). The gas-phase SO_3 then combines the vapor phase H_2O to form gas-phase sulfuric acid (H_2SO_4), and some of the SO_2 in the fluegases will also combine with water vapor in the fluegases and form gas-phase sulfurous acid (H_2SO_3) :

$$H_2O + SO_3 \rightarrow H_2SO_4 \text{ (sulfuric acid)}$$

$$H_2O + SO_2 \rightarrow H_2SO_3 \text{ (sulfurous acid)}$$

The collected fluegas (gaseous acid) in the flexible hose between the gas tip and the isolation valve will continuously condense into liquid acid, because the burner piping located outside the furnace cools down to atmospheric temperature, which is far below the sulfuric acid dew point of fluegas (about 120°C at 0.3 wt.% fuel oil, depending upon the concentration of sulfur trioxide and sulfur dioxide). Eventually, the liquid-phase sulfurous and sulfuric acids lead to severe corrosion.

This explanation may be somewhat confusing, because it is generally thought that the amount of fluegas flowing through the small gas-tip holes is negligible. However, in actual field operation, especially during cold weather, we have observed more than 50 mL of condensate inside the 1-in. flexible hose when the flexible hose is dismantled after one week of operation with fuel-oil firing only (no fuel-gas firing). Therefore, there is no doubt that the failure was the result of corrosion by fluegas condensation (see Figure 6 Detail 'A' for illustration).

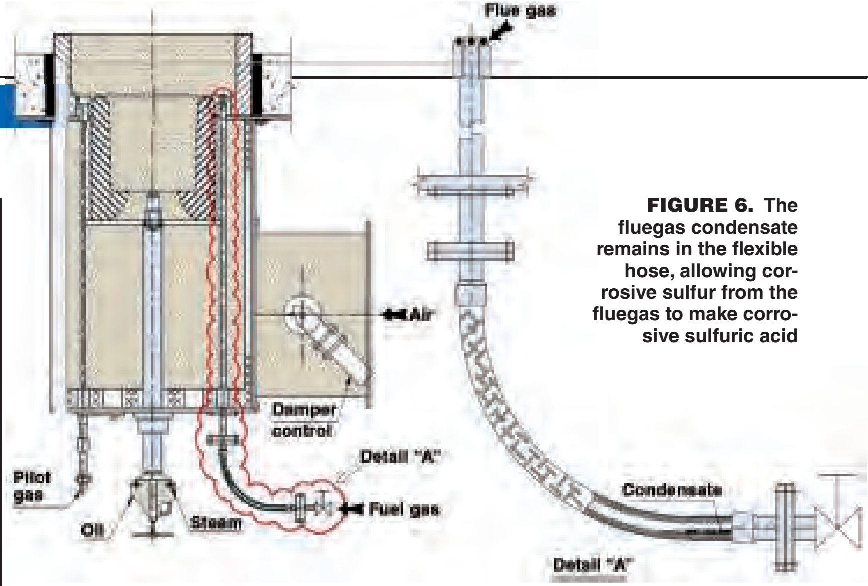

FIGURE 6. The fluegas condensate remains in the flexible hose, allowing corrosive sulfur from the fluegas to make corrosive sulfuric acid

Burner tip plugging

Liquids, particulate matter, unsaturated hydrocarbons and H_2S in fuel gas can cause most plugging problems. In order to identify the material causing the tip plugging, the fuel-gas analysis and the design review of the knockout drum that removes liquids from the fuel was carried out. However, there were no out-of-specification instances in the above-listed items. Nonetheless, the focus needed to be on the condensate from fluegas. It is important to recognize that the collected condensate will be carried over to the gas tip as soon as fuel gas is pressurized and serviced. Under continuous fuel-gas-

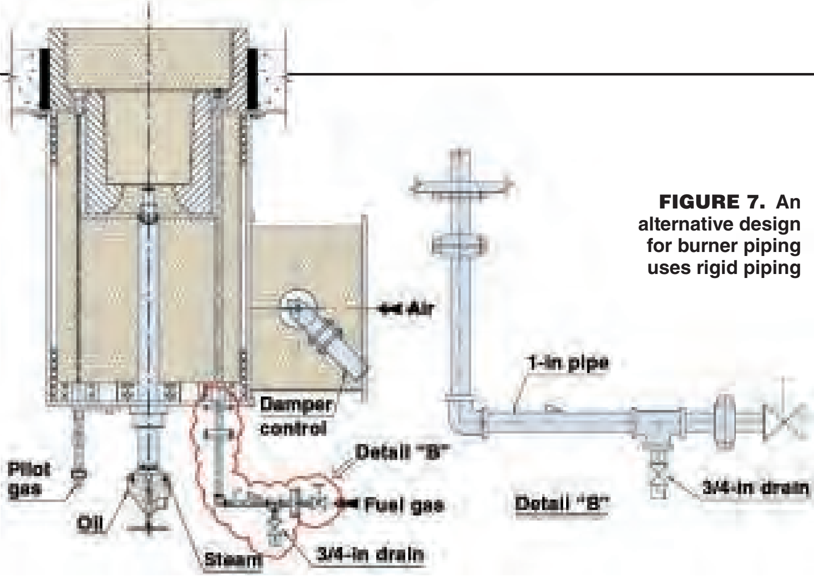

FIGURE 7. An alternative design for burner piping uses rigid piping

firing operating conditions, this may not be a problem because the tips are cooled enough by the high-velocity fuel gases flowing through gas tips. Upon switching from oil firing to gas firing, the condensate, which stays inside of the flexible hose, will automatically be delivered to the hot gas tip. This will lead to abrupt evaporation of liquid inside of the hot gas tip, and then result in plugging due to hydrocarbon coke build up, and finally to melting of the gas tip. Overheating the burner tips can cause the carbon in the fuel to thermally crack, giving rise to severe coking inside the tips, which leads to plugging of the holes.

Recommendations

Considering the above, it is highly recommended that the fuel-gas piping for combination-type burners that could possibly have fluegas condensation be designed with rigid piping (size 1 in. Schedule 40: 3.4-mm thickness) instead of flexible hose. The rigid piping is about 13 times thicker than flexible bellows tubes, as depicted in Figure 7. In real-world industrial practice, little is known about corrosion failure of rigid burner piping that may experience dew-point corrosion from fluegas condensation. It is possible that the thicker-walled piping could prolong pipe lifetime.

For gas-firing burners, the use of rigid piping is also recommended in the case of intermittent gas-firing burners that use high-sulfur fuel gas. If the use of flexible hose is not avoidable, then the material of the bellows tube should be Inconel 625, which is properly resistant to sulfur corrosion,

TABLE 2. RECOMMENDATIONS IN BURNER PIPING OF OIL-AND-GAS COMBINATION BURNER	
	Recommendations
Burner piping specification	• Rigid piping is preferred rather than flexible hose in order to prevent fuel gas leak due to acid dew point corrosion of fluegas. • Low point drain with slope is preferred in order to prevent burner tip plugging due to liquid carryover.
Code (API RP535)	• The requirement for preventing "fluegas acid dew-point corrosion in burner piping" should be clearly specified.

or stainless steel lined with PTFE (polytetrafluoroethylene) and flared-end fittings.

Periodic soap-bubble tests on the surface of the flexible hoses can eliminate the potential for accidental fires. Also, close visual monitoring can allow earlier identification of possible failures. During inspection, corrosion of a flexible corrugated metal hose can be spotted by looking for signs of chemical residue on the exterior of the assembly, or by pitting of the metal hose wall. The braid wires may become discolored from chemical attack and begin to fracture.

In order to prevent fuel-gas tip damage due to liquid carryover, a drain system at the nearest point from the burner gun should be provided at the lowest point of fuel-gas piping between the first block valve and burner tip (see Figure 7). Also, it is necessary that the activity of the liquid drain before gas firing should be strictly specified in the burner operation manual.

Considering the huge risk of damage by fire due to burner piping leakage, more consideration needs to be given to the revision of the code or specification. In case of the API RP535 2nd ed. (Burners for Fired Heater in General Refinery Services), it is highly recommended that the detail requirement for preventing "fluegas acid dew-point corrosion" should be clearly specified, in addition to the current mechanical requirement for flexible hoses (flexible hoses require special attention to avoid failure due to kinking). ■

Edited by Scott Jenkins

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Feature Report

Five Steps to Replacing Aged Heat-Transfer Fluid

Follow these guidelines to help ensure efficient operation of heat transfer systems, and proper exchange and disposal of aged fluids

Sarah Douglas and Conrad Gamble
Solutia Inc.

Changing out used heat-transfer fluid is critical to the efficiency of a heat-transfer fluid system. A well-operated heat-transfer-fluid system can enable efficient production, fewer shut-downs, less maintenance time and lower costs. In order to maintain a sound heat-transfer system, it is critical that the fluid is well cared for and, when the fluid reaches the end of its life, that it is efficiently changed out for new fluid. As fluid is used and ages, it can degrade to a point where it is no longer providing sufficient heat transfer for the process. When this occurs, the fluid must be evaluated and potentially changed out to restore the system to maximum efficiency. This article presents the general steps involved in determining: when a fluid should be replaced; draining the system; flushing and cleaning; complying with regulatory requirements for disposal of the used fluid; and refilling the system.

Step 1: Fluid quality

As organic heat-transfer fluids begin to age, they can break down into degradation products, begin to form solids and experience an increase in viscosity as shown in Figure 1. Process contamination, oxidation and overheating can also cause deterioration of fluid quality at an accelerated rate as described in Table 1. As these fluids experience higher viscosities and solid begin to form, the overall heat-transfer performance of the system can become less efficient.

In addition, the elevated viscosity and solids content will result in accelerated fluid degradation. This occurs because as the fluid moves through the heater or user, the turbulence is reduced with increasing viscosity and solids concentrations. This results in reduced fluid-side heat-transfer coefficients, increased retention time of the fluid within the coil, along with increasing film thickness adjacent to the heater-coil wall. The increased film thickness at the highest temperatures the fluid will experience leads to increased overall thermal stress to the fluid, and ultimately greater rates of thermal degradation. Generally, the result will be overheating of the fluid causing further degradation and potential coking. The consequences could be increased batch times, poor performance of the process and increased or unplanned maintenance time.

If the heat transfer system is not performing as expected, an initial review should be done to determine the cause behind the poor performance. This review should include sampling and analysis of the heat transfer fluid [*1*]. The quality of the fluid in the system can be telling in determining the cause for inadequate performance. For example, analysis may indicate that the acidity of the fluid is elevated above the standard range for organic heat-transfer fluids. This will most likely indicate that hot fluid oxidation or process contamination is occurring. This examination of fluid condition will allow the potential causes with the system to be narrowed down dramatically, making it easier to pinpoint the problem. In instances such as these, it is essential that the cause of the issue be determined and remedied before diluting or replacing the fluid. If the initial problem is not corrected, any additional fluid added to the system may be vulnerable to the same harmful influence. Analysis may also show that multiple parameters are elevated, indicating the fluid is simply reaching the end of its life. Fluid that has become severely degraded through age, or prematurely degraded through other factors, such as those listed in Table 1, will most likely require replacement to improve the system performance.

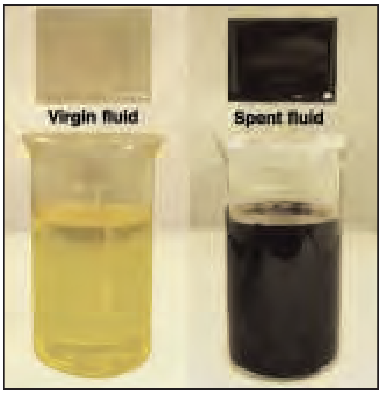

FIGURE 1. Virgin fluid (left) versus aged fluid (right) are shown here. Residue on the glass slides illustrate the deteriorated condition of aged fluid

Step 2: Draining

Once the fluid quality has been analyzed and found to be compromised, the system will most likely need to be drained. The initial action is to decrease the temperature of the heat-transfer system to 200°F and shut off the heater. The fluid should be allowed to continue to circulate in order to dissipate as much heat as possible [*2*]. One of the most common injuries sustained when working with heat trans-

TABLE 1. COMMON CAUSES OF ACCELERATED FLUID DEGRADATION

Cause	Description	Result
Contamination	Often occurs through heat-exchanger breach in the system resulting in the process-side material being released into the heat-transfer fluid. May also occur through accidental addition of incorrect material to the system during top up	The severity of the damage to the heat-transfer fluid will depend heavily on the type of process fluid. Generally process contamination can cause an increase in acidity resulting in potential corrosion, formation of solids and sludge, increase in viscosity and overall an increase in fluid degradation
Oxidation	Occurs when organic fluids are exposed to oxygen at elevated temperature. This reaction causes weak organic acids and other byproducts to form	Will cause an increase in the fluid's acidity, which may result in corrosion of carbon-steel surfaces. Over time it can result in high-viscosity fluid and an increase in solids formation
Overheating	Normally occurs when the velocity through the heater or user is below the design requirements, system upsets where the fluid becomes stagnant, or the temperature of the heater/process is elevated above design	Will cause the fluid to break down at an accelerated rate and form degradation products. Can result in coke forming on the heating coils or users. May also result in increased solids and sludge formation

fer systems is thermal burn. Cooling the system to below 200°F can minimize the risk of injury.

Once the fluid has been cooled to below 200°F, it can safely be drained through the use of appropriate procedures and personal protective equipment (PPE) from the system into drums, bulk containers or storage tanks for disposal. Seriously degraded fluids can have significantly elevated viscosities, which can impede effective draining if allowed to cool to lower temperatures. It is important to remove as much of the used fluid as possible to ensure minimal contamination of the new charge of fluid. Blowing the lines with nitrogen can assist in moving residual fluid to low points in the system where it can be safely drained and removed. The fluid manufacturer should always be consulted for specific guidance when draining a particular fluid.

The proper PPE should be worn whenever exposure to the fluid is possible. Suitable PPE for handling most heat-transfer fluids will be similar to what is expected in most plant environments. Chemical goggles, splash protective clothing and a face shield should always be worn when there is the potential for splashing of the fluid. Clothing that fully covers both arms and legs, closed-toed shoes and chemically resistant gloves are preferable.

Depending on the type of fluid being used, there may be vapor generation. In cases where the airborne exposure limit can be exceeded, such as in poorly ventilated spaces or during excessive vapor generation, the use of a respirator may be necessary. For most organic heat-transfer fluids, an organic mist cartridge should be adequate; however, the respirator manufacturer should always be contacted to confirm the appropriate type of cartridge. Despite the use of proper PPE, exposure to the heat-transfer fluid may occur.

In general, most heat-transfer fluids tend to be moderately irritating when exposed through skin or eye contact. When contact does occur, it is important to thoroughly flush the affected area with water immediately in order to prevent extended exposure and potentially worse irritation. It is also essential to ensure that employees working with a fluid are aware of its potential health effects, especially in cases of fluids with more harmful characteristics, and know appropriate actions should they come in contact with the fluid. Fluid suppliers typically include information on hazards and handling in the product's Material Safety Data Sheet (MSDS). The MSDS should always be consulted prior to draining the used fluid.

During the removal of the fluid from the system, there may also be leaks and spills around the system. It is important to immediately clean up any spilled heat-transfer fluid to avoid accidental contact or release into the environment. If the leak is significant enough to cause standing liquid, any free liquid should be pumped into a suitable container. Residual fluid can then be removed using absorbent material, such as mats or loose media. Once any remaining fluid has been absorbed, this material should be removed for appropriate disposal. Once again, the product's MSDS should be consulted to ensure that the fluid is handled properly and safely.

Step 3: Flushing and cleaning

Flushing the heat-transfer system prior to refilling with new fluid may be required if the system contained a severely degraded fluid that generated a large amount of sludge and solids. While sample analysis can offer a good indication on whether the system needs to be flushed, system indicators may also be helpful in determining if flushing is necessary. Symptoms such as increased batch times, temperature changes across heat exchangers, progressively longer heat-up times and higher fuel usage may indicate that the system requires flushing or additional cleaning.

Flushing the system will usually include filling the entire system with an organic flushing fluid and circulating this fluid at elevated temperature for a period of time. This process will allow excess residual material to be removed from piping and vessel walls and be swept out of the system by the flushing fluid. The flush fluid should then be thoroughly drained and disposed of properly before refilling the system with a fresh charge of heat-transfer fluid. When utilizing flush fluid, the specific guidance by the flush-fluid manufacturer should be followed closely. In addition, the manufacturer should be consulted on material compatibility with the system components and the replacement heat-transfer fluid.

In more aggressive cases where coking of the fluid has occurred, mechanical or chemical cleaning may be necessary. Coking generally occurs in systems where the fluid has been severely overheated. Mechanical cleaning involves physically removing coked material and solids from the system, by using methods such as hydro-blasting heat exchanger tubes or using a pipeline inspection gage (PIG) to clear blocked piping. Chemical cleaning may also be used instead of flushing or mechanical cleaning. This method tends to be more time-consuming, frequently includes multiple washes or treatments, and can generate a significant amount of waste that will require proper disposal.

While chemical cleaning can be effective in many systems, it is not a foolproof method of removing coke-like deposits. Before considering chemical cleaning, bench-scale analysis should be done with deposit samples from the specific system. This will help ensure that the coke material can be effectively removed, and avoid potentially costly procedures that do not sufficiently clean the system.

Once the system has been thoroughly cleaned, a visual inspection should be performed before refilling with fresh fluid. This inspection should confirm that residual material — especially in low-flow areas, such as storage and expansion tanks — has been thoroughly removed and that the new charge of fluid will not be significantly affected.

Step 4: Regulatory requirements

Synthetic heat-transfer fluids can be categorized as a hazardous waste under the Resources Conservation and Recovery Act (RCRA) when sent for disposal. A hazardous waste, as defined by the U.S. Environmental Protection Agency (EPA), is a solid waste that has been identified to be ignitable, corrosive, reactive or has toxicity characteristics [*3*]. Synthetic heat-transfer fluids may be identified as hazardous waste due to the toxicity characteristics category, unless contaminated by another material that meets one of the other qualifications. One compound that could qualify heat-transfer fluids as hazardous is benzene, which the EPA sets at a regulatory level of 0.5 mg/L [*4*]. These regulations are implemented by the EPA, however individual states may have more rigid regulations.

Used heat-transfer fluids may qualify under the EPA Standards for the Management of Used Oil (40 CFR 279). Used oil regulations are an amendment to RCRA that allow "on-spec" used oil that could potentially be characterized as hazardous waste to be recycled or used for fuel instead of disposed of [*5*]. The cost of disposing of a fluid as a used oil instead of a hazardous waste can be significantly less and, in many cases, the used-oil dealers will purchase the used oil. Used-oil dealers must comply with the EPA used-oil regulations and ensure that the fluid to be reclaimed meets the used-oil criteria. The requirements for a fluid to meet the specification for "on-spec" used oil are listed in Table 2 [*6*].

TABLE 2. EPA REQUIREMENTS FOR USED OIL

Constituent or property	Allowable level
Arsenic	5 ppm maximum
Cadmium	2 ppm maximum
Chromium	10 ppm maximum
Lead	100 ppm maximum
Flashpoint	100°F minimum
Total halogens	1,000 ppm maximum

In addition to meeting these requirements, the oil must be synthetic or refined from crude oil and it must have been used [*7*]. A fluid that has been operated in a heat-transfer-fluid system will typically qualify by the EPA as being used. As indicated above, individual states may have more stringent requirements when it comes to qualifying fluid as used oil. In addition, it is up to each state whether or not to adopt the EPA used-oil regulation. Before considering used-oil generation or disposal, it is advisable to consult a state authority to learn the specific state requirements for used-oil generation and disposal.

The disposal of absorbent material used during cleanup of small spills or releases of used oil may also qualify under the used oil regulation. If the material is to be burned for energy recovery it can be disposed of as used oil. If the material is not to be disposed of as a used oil, it should be completely drained and then undergo a hazardous waste evaluation [*5*].

If used oil is stored at a facility before being transported to a used-oil dealer, it must be stored in a structurally sound container and labeled appropriately. Each drum or container must be clearly labeled as "used oil" as shown in Figure 2 [*8*]. Once ready for disposal, the fluid must be transported by an operator that has an EPA Identification Number to transport used oil [*9*].

FIGURE 2:. Used oil should be stored in clearly labeled drums

If used oil is being stored at a facility, it is also important to follow the EPA standard for dilution or mixing of waste material. The EPA prohibits the use of dilution as a means to lessen the components in a waste that would characterize it as hazardous. In other words, if any amount of a listed hazardous waste is combined with a non-hazardous waste then the entire mixture becomes hazardous. Fortunately, this should not apply to most used heat-transfer fluids, as they are generally not listed hazardous wastes. However, if there is a listed hazardous waste generated at the manufacturing site, it is important that it not be disposed of in the same container as the used oil, since this would then classify the entire volume as a hazardous waste [*5*].

The storage of used oil will also fall under the Spill Prevention, Control, and Countermeasures (SPCC) rule as regulated by the EPA (40 CFR 112). This rule requires facilities to put in place appropriate procedures to prevent oil spills, as well as measures to contain and respond to a spill should one occur [*10*]. The ultimate goal of the SPCC is to minimize oil release into the navigable waters or adjoining shorelines of the U.S. If a facility has the potential to release a significant

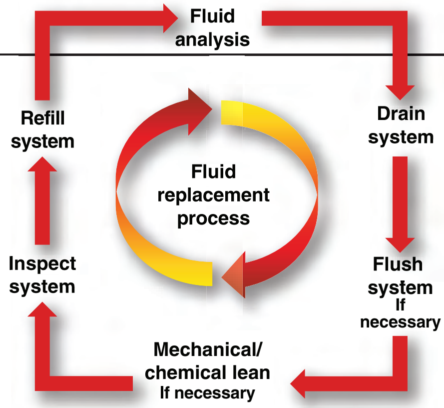

FIGURE 3. Common steps involved in replacing aged heat-transfer fluid

amount of oil into navigable waters it will most likely need a SPCC plan in place to be in compliance with the EPA regulation [*11*].

If used oil is not sent to a used-oil dealer for recycling, or burned for energy recovery, it must be disposed of as a hazardous or nonhazardous waste depending on the material. If the used fluid meets the definition of a hazardous waste under the applicable regulation, then it must be disposed of as such. If the used fluid does not meet the definition of a hazardous waste, then it may be disposed of as a solid waste in accordance with the EPA regulation. Due to the cost of these disposal methods, it is advantageous to dispose of used heat-transfer fluid as "on-spec" used oil when possible.

Step 5: Refilling

Once the used fluid has been removed from the system, and the system has been cleaned if necessary, the new charge of fluid can be added. Before adding the new fluid, it is important to ensure that all drain valves have been closed, that any maintenance on the system has been completed, and that the system has been restored to normal operational readiness. The fluid can then be added to the system. The system should be filled from the bottom to effectively expel any air or gas bubbles and to avoid splashing and aerating the fluid. Once the system is fully filled, the fluid can begin to be circulated and the heater can be turned on. The system should be slowly heated and then held at just above 100°C to dispel any residual moisture that may have been introduced during the system fill. Any excess moisture present in the system should be vented, typically from the expansion tank, then the temperature can be elevated to operating conditions. The standard process for replacing aged heat-transfer fluid is illustrated in Figure 3.

It is important that proper care is taken when removing used fluid from a system, through the disposal process and when refilling with fresh heat-transfer fluid. Effective management of heat-transfer-fluid replacement can minimize turnaround time, system downtime and the occurrence of unexpected incidents. ■

Edited by Gerald Ondrey

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Integrating Gas Turbines Into CPI Facilities

Capturing hot fluegas from gas turbines for use in process plants can yield benefits, but tradeoffs must be considered

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To realize the best possible thermal efficiency, gas turbines should be integrated into chemical process industries (CPI) plants, but doing so can be difficult and requires special consideration. Specifically, in some CPI units, while the turbine's shaft is driving an equipment component (such as a compressor), the hot exhaust gas from the gas turbine can be connected to furnace burners or waste-heat-recovery units.

The main challenge for such a complex, integrated configuration is to maintain overall system operability for both upstream and downstream components. One possible configuration would involve connecting a gas turbine to several furnaces or waste-heat-recovery units. Another configuration may involve several gas turbines connected to a large waste-heat-recovery module.

This article discusses how to integrate gas turbines into CPI plants, and provides tips on how to operate and maintain such integrated systems.

Integration issues

A considerable amount of heat is generated when the hot exhaust gas (hot fluegas) is vented from a gas turbine, and unless the stream is captured for some other purpose, this heat energy is wasted. The goal of any gas-turbine-integration effort is to engineer a system that makes best use of the heat discharged in the turbine's exhaust gas. However, a variety of tradeoffs must be reconciled when assessing the pros and cons of different operating scenarios. Efforts to integrate gas turbine(s) into a downstream CPI unit should consider the performance, lifetime, operation and safety issues of the entire integrated system. Several options exist to make use of the waste heat from a gas turbine. For instance, the fluegas can be used to heat the following:

- The burners of a CPI furnace
- A heat-recovery system (typically, using a waste-heat-recovery steam generator, HRSG, to support the plant's steam requirements)
- An afterburning system (such a system uses burners to reheat the turbine's fluegas stream for downstream applications that require higher inlet temperatures)

Several important factors must be considered during any turbine–integration effort in a plant setting:

- *The gas turbine type and model*. Gas turbines are not typically custom-designed machines; rather, they are often selected from existing commercial models
- *The expected and acceptable load changes required by driven equipment load (most often a compressor, but sometimes a generator)*. Some driven equipment can work with a wide range of loads (such as variable-speed centrifugal compressors), but others are constant-speed, constant-load machines
- *The hot gas requirement range*. When a gas turbine is integrated with another mechanical system at the facility, the integration team must define both the acceptable flow, temperature and pressure ranges of the hot gas that is available in the gas-turbine exhaust, and the requirements of the downstream CPI system that will use that stream

FIGURE 1. Shown here is an example of a modern aero-derivative gas turbine installation, which uses a 40-MW gas turbine. The inlet air filter, the accessories, auxiliaries and the exhaust-gas stack are shown. The exhaust gas stack is located behind (right side of the photo), at a higher elevation with sufficient distance to the air-intake location

In an integrated design, the performance of the downstream CPI system depends closely on the turbine's working regime, and this level of uncertainty can make the CPI plant system difficult to control. On the other hand, the CPI system operation could also affect the exhaust-gas pressures and parameters, and consequently may impact the upstream gas-turbine operation. The primary challenge is how to integrate the gas turbine and the CPI unit in the most appropriate way, so that each can meets its own operational objectives without compromising its required operational flexibility.

Oxygen levels

The oxygen concentration in the exhaust stream produced by most gas turbines is usually around 10–18 vol.%. However, the combustion process in a gas turbine typically consumes only a small portion of the oxygen from the intake air (thereby leaving residual oxygen in the exhaust stream). This makes it possible to use a supplementary firing system (in the form of a CPI furnace burner or afterburner), to increase the heat-rate of the exhaust stream (in other words, to increase the temperature of the fluegas).

For such a configuration, a separate burner unit (afterburner) can be used to reheat the fluegas, before it goes to the target downstream operation.

The use of an interim afterburner unit can help to increase the overall operational flexibility of the integrated configuration, by allowing operators to adjust the heat value of the exhaust stream to meet the needs of the downstream system. With such a setup, the fluegas should be routed from the gas turbine exhaust to the afterburner unit using proper ducting system (called a hot-gas handling system).

In addition to the heat value of the fluegas flow, another issue to consider is that the fluegas from a gas turbine is often turbulent and unevenly distributed. When designing an integrated configuration, steps should be taken to ensure a more-uniform fluegas distribution (to the maximum extent possible) in the hot-gas handling system — particularly in the transverse section of the hot-gas ducting.

Efforts to reduce this turbulence will bring many operational and technical benefits. For example, pollutant levels produced in the emissions from the separate burner unit will be impacted by several factors, including the unevenness of the upstream fluegas flow to that unit, local velocities, and temperature distributions (such as the temperature variations through the transverse section).

Most afterburner systems are designed to work directly with gas turbine fluegas (and thus to tolerate some variation in fluegas flow conditions). Other afterburner systems are designed to accept fresh air (instead of fluegas) — for instance, when the gas turbine is tripped — to ensure uninterrupted operation of the downstream CPI systems.

For a CPI system (whether a furnace, a heat-recovery system, or other), the working regimes and the temperature distributions in different sections (such as the minimum acceptable gas-flow temperature in a heat-recovery steam generator system) should be evaluated based on the different operating modes of the gas turbine and the afterburning system. The complete operating range, including the full minimum and maximum conditions, should be identified.

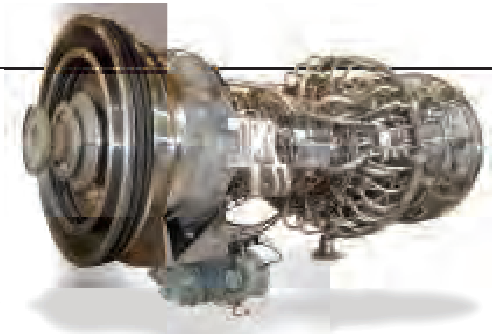

FIGURE 2. **In the core of a large aero-derivative gas turbine shown here, one can see the combustion system with supporting air compressor and turbine sections**

Overall, the use of an afterburner system is a good option to help compensate for variations in the gas turbine operation (such as environmental conditions or variable load) that could impact the operation of downstream, integrated CPI systems.

Case study 1

Discussed next is a case study to demonstrate the integration of a gas turbine into a CPI plant. In this study, the gas turbine exhaust gas is connected to the furnace burners to supply hot inlet air, while the turbine shaft is coupled to a generator to produce electricity for the CPI facility.

Scenario 1. Initially, the gas turbine selected for this application was a heavy-frame, single-shaft two-bearing machine with approximately 33% efficiency. Simulations show that this gas turbine can offer limited flexibility in terms of the load/speed variation and the fluegas generation. However, if this heavy-frame, single-shaft gas turbine is used for the integration effort, a very complex arrangement, including a hot-gas bypass and trim-air system, is required.

For instance, with this configuration, the gas turbine has a limited capacity to increase its own fluegas generation, so it would be necessary to introduce some ambient air (fresh air) when the volume of the fluegas required by furnaces exceeds that produced by the turbine itself. This is known as the trim-air system. And because the gas turbine cannot reduce its own fluegas volume, a bypass system would be required for use, when less fluegas is required by the furnaces.

As a result, to ensure the needed operational flexibility, steps must be taken to control the hot-air flow and the temperature of the exhaust gas that goes to the downstream burners. This is done by implementing a source of ambient air after the gas turbine (the trim-air system) and a bypass system for the hot fluegas.

Providing a stream of fresh air for the downstream — to ensure uninterrupted furnace operation when the gas turbine is tripped — is a relatively easy (and necessary) job. However, the introduction of fresh air (trim air) to the fluegas stream itself involves more complex engineering, because the hot exhaust-gas stream is at elevated pressure and can have other variable conditions.

As shown in this case study, the use of a heavy-frame single-shaft, two-bearing gas turbine will result in an integrated system that is inefficient, expensive and potentially risky for system operators. As a result, this initially selected integration scenario was rejected.

Scenario 2. Next, the use of an aero-derivative gas turbine was studied, as this design offers much greater flexibility and improved overall thermal efficiency. The selected gas turbine is a multi-spool, aero-derivative machine, which exhibits a relatively large operating load range and excellent flexibility (mainly because of its multi-spool design), with around 43% efficiency. In this case, the simulations confirmed that the flowrate and temperature of the turbine's hot exhaust gas will not deviate from the minimum and maximum requirements of the downstream furnaces, even under various operating scenarios. Choosing a flexible gas turbine can help to maximize overall CPI plant flexibility and operability.

In several situations that were studied for this case scenario — such as a trip of one or two furnaces, maximum or minimum burner loads and so on — the aero-derivative gas turbine was able to react in a fast and timely manner to adjust the required flow of hot gas. While such an integrated configuration would cause the electricity generation in the CPI plant to change under different operating conditions, the gas turbine's inherent flexibility would allow the unit to maintain electricity generation within defined limits (and if necessary, additional electricity can be exported, or make-up electricity can be imported from the grid).

One of the interesting operating cases studied for this scenario is when two of the total eight furnaces have tripped; the gas turbine should be unloaded to the minimum electrical generation load. Based on the simulations, the gas turbine was shown to manage this load reduction in an acceptable way (so the generated fluegas was suitable for use by the remaining six working furnaces).

In general, today's aero-derivative gas turbines offer a variety of advantages over heavy-duty industrial-frame models. For instance, extremely high firing temperatures are now possible in aero-derivative units, ensuring high efficiencies (above 45%). Market pressures for higher thermal efficiencies have resulted in more widespread use of such aero-derivative gas turbines today.

Meanwhile, CPI plant availability can be improved thanks to the flexibility of these gas turbine designs, because the main modules (such as the combustion module) in most of today's aero-derivative gas turbines can be completely changed out within 48 hours — a vast improvement over the 14 days that are typically required for major repairs of heavy-duty industrial-frame gas turbines. Other advantages include:

- *High starting-torque capacity.* Excellent torque-speed characteristics can allow a large CPI machinery train (driven by the gas turbine) to start up efficiently (For example, in a CPI compressor-drive application, this ensures predictable startup capabilities under settle-out pressure conditions)
- *Relatively easy installation.* This results from the compact and light design of today's aero-derivative units

FIGURE 3. The modern aero-derivative gas turbine installation shown here includes a 100-MW gas turbine. The inlet air system, gas turbine and exhaust gas system are also shown

Operation and maintenance

Annual expenditures for maintenance on a gas turbine may average 5–11% of the initial purchase price. Operation and maintenance programs are typically prepared with a special focus on critical areas, such as the hot-gas-path, turbine blades, and bearings, with the goal of avoiding frequent shutdowns, reliability issues, safety problems, explosions or hazardous situations. The key is good planning.

For gas turbines that are integrated with other CPI systems, the maintenance philosophy should be defined as early as possible — preferably before or at the basic design stage of the CPI project, — since decisions made at this point will directly affect the type of gas turbine and specification details. Once the gas turbine is purchased, the available options for the maintenance practice will narrow.

Many CPI operators choose the aero-derivative gas turbine because of the inherent advantages of its package approach (that is, the modular construction that uses the smallest-possible number of skids). In general, CPI operators have two primary options for gas-turbine maintenance:

1. Remove the gas turbines and send them to the vendor's facilities for periodic overhauls
2. Operate an in-house maintenance facility to carry out most of the routine overhaul activities

If the operator owns many identical units, the savings associated with maintaining an in-house maintenance facility can easily cut the maintenance budget to less than 60% of that required using the first approach.

The operating philosophy of the CPI facility will also be important when deciding which approach to take for gas turbine maintenance. For instance, sometimes a time-based maintenance approach is selected. In this way, the operator will run the gas turbines without a shutdown for a certain period of time, and then overhaul them on a regular basis. This tends to be an old-fashioned, inefficient approach.

By contrast, condition-based maintenance is preferred. It is much better to run every gas turbine until it shows some sign of distress before carrying out an overhaul. This reduces the number of overhauls required over the life of the asset.

However, the use of condition-based monitoring requires more monitoring and routine inspections to avoid catastrophic failure. To reduce unnecessary maintenance costs, the key decision is to avoid shutting down any gas turbine for an overhaul unless there is a scientific reason for doing so.

Gas turbine monitoring

Condition-monitoring systems for gas turbines are, without a doubt, the most complex of any form of machinery in a CPI plant, and many competing strategies are available. Each condition-monitoring system should be the right one for a given operator, in a given CPI plant, for a given type of gas turbine (for example, the single-shaft or multi-shaft models). The extent, timing and duration of inspections and monitoring will vary by facility, and are determined by factors including:

- The gas turbine model
- The environmental conditions
- The permissible downtime
- The fuel type and quality
- The operating mode

Condition monitoring involves the observation and analysis of observable parameters, and the use of the resulting data to assess the internal condition of the gas turbine by estimating the expected run length and predicting potential failure. A variety of online condition-monitoring methods are available, including vibration monitoring, oil analysis, wear-debris analysis, performance monitoring and temperature monitoring, and all of these tactics are used extensively for gas turbines in CPI plants.

In many CPI plants, the operation and maintenance schedule of the gas turbine does not mesh very well with the downstream plant-operation planning. Sometimes, a gas turbine is shut down because of a problem in another part of a CPI plant, and this provides an opportunity for some minor inspection or offline monitoring (such as a bore-scope inspection). CPI operators often rely on a plant-specific mix of condition-monitoring data, fired hours, and gas-turbine operation-history information to determine the most appropriate gas-turbine run length.

Oil analysis and wear-debris analysis programs are useful early-detection methods, as they reveal the presence of small metal particles and oil deterioration, which can be used to evaluate the condition of critical turbine components (such as lubrication-wetted components), and get an early warning of impending distress. Similarly, when oil analysis and wear-debris analysis are used together with vibration monitoring, bearing condition can be assessed.

With the spectrometric oil-analysis method, metals in the lubrication oil are measured, with rising levels indicating excessive wear. Data can be trended over time and compared to baseline values.

Similarly, magnetic plug analysis is particularly useful for aero-derivative gas turbines, which are equipped with rolling-element bearings.

To carry out vibration monitoring, vibration sensors (probes) are installed at predetermined locations to record vibration data, which should then be compared to the available data (such as harmonic frequencies) to identify incipient problems.

However, the use of vibration monitoring for gas turbines can be challenging due to high temperatures in and around the gas turbine. Specifically, more care in terms of the sensor/hardware installation location and details should be taken for aero-derivative units because of their very compact design and the high temperatures at sensors and hardware locations.

The simplest form of performance monitoring involves the trending of key operating variables (such as pressure, pressure ratio, temperature, air-compressor speed, turbine speed, fuel consumption and others) and comparing these plots with corresponding baseline values. For CPI plants, the aero-derivative gas turbines are usually variable-geometry gas turbines (for example, designs that include variable guide vanes). These gas turbines present greater challenges when it comes to performance monitoring.

A thermodynamic gas-path analysis can be used for aero-derivative gas turbines or variable-geometry gas turbines. This analysis typically involves an iterative process of matching the performance of the air compressor with the turbine section for a given operating case (such as an output speed and an exhaust-gas temperature)

Meanwhile, detectors can also be used to track particles in the fluegas. Rising levels of entrained particles provide an indication of rubbing or other malfunctions, such as disc- or blade-creep fatigue.

Other types of condition-monitoring efforts include the study of transient characteristics, such as turbine-ignition temperature spikes during accelerated startups, startup acceleration times and coast-down times. Meanwhile, a possible surge in the air-compressor (the axial air compressor in the gas turbine) can occur as a result of severe degradation or serious problems in an air-inlet system.

For many gas turbines, the root causes associated with degraded performance stem from issues in the combustor and hot-end section. Typically, modern aero-derivative gas turbines have more than 22 bore-scope ports that provide access to critical components in the core of the gas turbine.

Bore-scope inspections are usually scheduled once a year (specifically, at 6,500 operating hours for turbines using a natural gas fuel, or once every 4,000 operating hours for turbines using a fuel oil). The first bore-scope inspections after around 1,000 operating hours serve can help to establish useful baseline data.

Similarly, the images should be compared to the pictures from past inspections to recognize changes; the resulting insight can help the team to establish the most appropriate, proactive maintenance schedule. The decision to open a gas turbine section for further inspection is usually based on the result of bore-scope inspections.

Case study 2

This next case study is for a CPI unit that uses aero-derivative gas turbines to drive a compressor, and turbine exhaust flows to an afterburning system and heat-recovery steam generator to produce high-pressure steam for downstream use in the CPI facility. The gas turbine-compressor trains should operate at the variable operation modes (such as variable-speed and variable-load modes).

In general, the fluegas from the aero-derivative gas turbines has a relatively low temperature compared to the exhaust temperature of similarly sized, heavy-duty industrial gas turbines. Thus, the afterburning system is used to increase the fluegas temperature prior to its downstream use. This added step helps to boost the overall efficiency and flexibility of the integrated system.

The afterburner module is typically designed using refractory steel, using an advanced arrangement to ensure the required temperature and flow uniformity. The afterburner system can boost the exhaust gas temperature to the range of 500–750°C.

The HRSG is a fire-tube type boiler with two fluegas lines — one horizontal and one vertical — comprising different sections (including the superheater section and the saturated steam section). The superheater section has more stages and tube bundles.

Both radiation and convection heating can ensure a relatively uniform temperature in the generated steam, even for a large range of loads. The generated steam temperature will be maintained at relatively constant levels (within acceptable limits) in the wide range of 70–100% of the thermal load of the gas turbine.

For the first proposed design in this case study, the simulations at various working regimes of the HRSG show high localized temperatures in the superheated steam section (compared to the rated temperature), which could lead to some operational problems. Some localized high temperatures and extreme hot spots are identified in the simulations.

To achieve the optimum steam velocity and temperature regime, the exchange area of the superheater section was optimized by replacing the first two coil pipes with two L-shaped pipes. This redesign was successful in modifying the temperature distribution and led to a better temperature distribution (without localized temperature excursions or hot spots) compared to the initial design case.

For this integrated configuration — involving an aero-derivative gas turbine plus an afterburning unit plus an HRSG — the HRSG load can be varied by adjusting the afterburning parameters to meet CPI plant requirements. Such a setup can maintain relatively constant steam generation regardless of load changes in the upstream aero-derivative gas-turbine load.

CPI plants can benefit greatly from using today's newer aero-derivative gas turbines, as they offer greater flexibility and higher efficiency compared to traditional turbine options. Integrating these newer gas turbines with downstream CPI operations to capture the waste heat contained in the turbine fluegas stream can provide benefits, as long as optimization efforts are carried out to ensure proper upstream and downstream integration. ■

Edited by Suzanne Shelley

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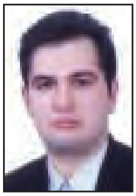

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Responding to Environmental Inspections

A regulatory inspection can occur at any time. The best way to successfully handle an inspection is to be prepared for it before it happens

Margaret M. Witherup
Gordon Feinblatt LLC

One of the most unsettling experiences in a company's existence may be the surprise regulatory inspection by a representative of the U.S. Environmental Protection Agency (EPA) or a State Environmental Agency. What if you refuse to let them in? What are your rights? How can you best ensure that the inspection goes smoothly? This article briefly summarizes the government's environmental inspection authority and provides some practical tips on how to prepare for and survive an environmental inspection.

Preparing for an environmental inspection should be viewed as any other necessary business activity. A company's best chance of successfully surviving an environmental inspection is to be prepared for it before the inspector is knocking at the door. This involves both reviewing the company's compliance with applicable regulations as well as having a plan in place for handling an inspection when it occurs.

Governmental authority

Most environmental regulatory agencies have broad inspection authority to determine a company's compliance with the environmental laws and regulations that the agencies enforce. In many cases, this includes the authority to inspect processes and monitoring equipment, to copy records, and to take samples of materials stored or used at the facility, as well as discharges and emissions from the facility.

An inspection may be limited to a single issue (such as compliance with the company's air permit), may be a "multi-media" inspection intended to determine a facility's compliance with all applicable environmental laws and regulations, or may be in response to a specific complaint (for example, a neighboring property-owner's complaint about runoff or dust from your facility). The scope of an inspection will be determined by the purpose of the particular visit.

If your facility has an environmental permit, the permit likely includes a condition granting the issuing agency the right to inspect your facility for the purpose of determining compliance with the permit. If you refuse to let the inspector enter, you may be in violation of your permit and the inspector may be able to return with a search warrant, sometimes even on the same day. A potential advantage of denying access is that it may provide a brief chance to correct problems. However, denial of access may lead the inspector to believe the company is hiding something and you will have lost whatever goodwill you may have otherwise had with the inspector. If there is any doubt as to what inspection authority an agency has in a particular situation, consult with legal counsel immediately.

Preparing for an inspection

Companies should assume that an environmental investigation may occur at any time and have a general plan for what should happen when an inspector arrives. Companies should designate an official who is authorized to allow an inspector access to a facility and who will be the inspector's primary point of contact, as well as a backup person in case the primary contact person is not available.

The best way to ensure that an environmental inspection goes smoothly is to be in compliance with all applicable environmental laws and regulations pertaining to your operations. Know your company's operations, keep your permits up-to-date, and understand what your responsibilities are. Environmental compliance documents, such as inspection records and logbooks, should be organized and physically segregated from internal or privileged documents that would not normally be subject to inspection (for example, compliance audits and/or attorney-client-privileged communications).

If you do not have the necessary environmental expertise in-house to determine whether your facility is in compliance, consult with an experienced consultant or environmental counsel. Consider conducting an internal environmental audit to identify and correct any deficiencies before an inspector arrives. Use a checklist to make sure you don't inadvertently overlook something. Once you are satisfied that your facility is in compliance, periodically review your operations to make sure they remain in compliance with the latest regulatory developments.

What to do during the inspection

When government inspectors show up at your facility, consider the following actions:

1. Immediately notify the appropriate company official. If an environmental inspector is on-site, immediately notify the company official who has been designated to be the agency's primary point of contact. Ask the inspector to wait until the designated person arrives to escort him or her around the facility.

2. Review the inspector's credentials. Only authorized government officials are allowed to conduct inspections. Local citizens or environmental advocacy groups generally do not have the right to enter and inspect private property without the property owner's knowledge and informed consent.

3. Let them in (or refuse entry in limited circumstances). Although there are a few valid reasons for denying a government inspector access to a facility, entry should be refused only if there is a compelling reason to do so, such as if the inspector does not have the safety equipment required by the facility (see Item 5, below).

4. Determine the scope. Request an initial conference and an explanation of the scope of the investigation. If the inspector indicates that it is a criminal investigation, consult with an attorney and ask the inspector to wait for the attorney to arrive at the facility. Make sure that the inspection is conducted in strict compliance with the search warrant.

5. Be safe. Require all inspectors to take the same types of safety precautions that employees and visitors are required to take. If this includes the use of hard hats, safety goggles, or other personal protective equipment, then the inspector should wear the same equipment and take the same precautions, just as any employee or visitor would.

6. Be courteous. Treat visiting government inspectors with respect and courtesy. An inspection can provide an opportunity to develop a good relationship with an inspector with whom the company may have to deal for many years to come.

Be responsive and provide the inspectors with the information they ask for, but also be careful what you say. You do not have any obligation to volunteer additional information. If you do not know or don't have the information they are asking for, do not speculate or guess at the answer. Simply indicate that you will find out the answer and provide it in a timely manner. Never misrepresent facts or lie to an inspector.

7. Accompany the inspector everywhere. No matter how busy you are, do not let the inspector wander around the facility unattended. The designated company representative should accompany the inspector throughout the facility. Try to avoid taking an inspector anywhere that is not within the scope of the inspection, but be careful about denying access to an area of the facility that the inspector specifically asks to see, as that may lead the inspector to think you have something to hide and they may be able to return with a warrant.

Take notes on what the inspector observes and any particular items of interest. If they take samples of any materials or discharges from the facility, take duplicate samples and request copies of laboratory analytical results and any photographs taken by the inspector.

8. Manage document productions. Environmental regulations and permits require many types of documents to be kept, and these are all "fair game" in an inspection. This does not mean that the inspector is entitled to see every single document at the company's facility. Many documents will be unrelated to environmental issues or may be privileged or confidential. If there is any doubt as to whether an inspector is entitled to view a particular document, consult with legal counsel.

9. Protect confidential business information. The information obtained by the inspector during the inspection may be subject to public disclosure under the Federal Freedom of Information Act or state equivalent. There are, however, several categories of information that are exempt from public disclosure, such as confidential commercial or financial information, trade secrets and so on. If any portion of your company's process or documents is confidential, advise the inspector so that he or she can take appropriate precautions.

10. Request a post-inspection debriefing. At the end of the investigation, request an exit conference with the inspector to learn of any potential adverse findings. Always request a copy of any written statement of observations or final inspection report. If the inspector identifies a need for follow-up action or potential violations, fix any violations quickly and then send a note to the inspector requesting a re-inspection. Demonstrating to the inspector that you are a responsible business trying its best to comply with all applicable laws and regulations may minimize the chance of enforcement action or fines. ■

Edited by Dorothy Lozowski

Author's note

This article is intended for general informational purposes only and is not legal advice to any person or entity.

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Fractionation Column

Ruptured rupture disc

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

It was Terry Thurber's idea. It was a bad idea. But Bob Miller and Nick Urbanski taught me many years ago that, in the research and development (R&D) world, bad ideas are often the best ideas. Install things upside down or turn them inside out. R&D managers will be surprised at what can be learned. Thereafter, file what was learned under "We Learn More From Our Failures Than Our Successes."

Terry's bad idea: Blow the FRI steam-system rupture disc and videotape it! I was worried that we would be stressing a set of pipes that had not previously seen high pressures. I checked with Terry's foreman, Fred Smith. Fred explained that, for several years, FRI would regularly blow this particular rupture disc until we learned that it was occasionally subjected to vacuum operation, which was weakening the old discs. After we figured that out, we started using rupture discs that were rated to withstand occasional vacuum excursions. We decided to blow the disc — and videotape it.

When the big day came, we set up five video cameras. Three were focused on the rupture disc, which was about 70 ft up. One was focused on the control-room control board. One was focused on an outdoor pressure gage. From each camera, we collected about 15 minutes of footage. The disc was rated to blow at 175 psig at 150°F. That day, it ended up blowing at 153 psig, but at a much higher temperature. As expected, the event was loud. When the disc blew, the long vertical pipe underneath it lurched backward much too far. Later, mechanical changes were made to better anchor the pipe. That wasn't the fun part.

FRI's video footage includes audio. When listening to the footage, as the steam system's pressure is being increased, several birds are chirping contentedly and incessantly. At about 145 psig, the birds go suddenly and totally silent. At about 148 psig, one of the birds starts tweeting out an SOS as if it knows Morse Code: dot-dot-dot-dash-dash-dash-dot-dot-dot. About halfway through the warning message, two of the birds fly away in a panic. The disc blows about five seconds later, when the two birds are a safe distance away. They heard or felt something before we did, before the disc ruptured! Do birds have instincts, or premonitions?

FRI took the 75 minutes of video footage and pared it down to 12 minutes. Views from all of the cameras are included. Audio tracks from two of the cameras are included. I would not have believed the birds tweeting out an SOS if I did not see it (and hear it) for myself. Do you believe it? If not, come see the 12-min video at the Henry Kister Symposium at the AIChE Spring Meeting (San Antonio, April 28–May 2; www.aiche.org). And more importantly, the next time that you hear a bird tweeting out an SOS, don't look up! ■

Mike Resetarits

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11	26	41	56	71	86	101	116	131	146	161	176	191	206	221	236	251	266	281	296	311	326	341	356	371	386	401	416	431	446	461	476	491	506	521	536	551	566	581	596
12	27	42	57	72	87	102	117	132	147	162	177	192	207	222	237	252	267	282	297	312	327	342	357	372	387	402	417	432	447	462	477	492	507	522	537	552	567	582	597
13	28	43	58	73	88	103	118	133	148	163	178	193	208	223	238	253	268	283	298	313	328	343	358	373	388	403	418	433	448	463	478	493	508	523	538	553	568	583	598
14	29	44	59	74	89	104	119	134	149	164	179	194	209	224	239	254	269	284	299	314	329	344	359	374	389	404	419	434	449	464	479	494	509	524	539	554	569	584	599
15	30	45	60	75	90	105	120	135	150	165	180	195	210	225	240	255	270	285	300	315	330	345	360	375	390	405	420	435	450	465	480	495	510	525	540	555	570	585	600

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* International Edition

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Classified Index March 2013

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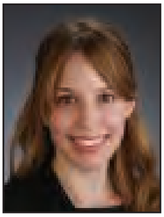
People

MARCH WHO'S WHO



Boyens

Lainé

Distaso

Duncan

Siegel

Helmuth Möhwald is elected as a member of the Academia Europaea, a European non-governmental association whose memberships includes experts in technology, medicine, mathematics, economics, the law and more. He is director of the department of interfaces at the **Max Planck Institute of Colloids and Interfaces** (Potsdam, Germany).

Kerri Boyens becomes product manager for the Torayfan Polypropylene Film Div. of **Toray Plastics America** (North Kingstown, R.I.).

Samsung Engineering (Seoul, South Korea) appoints *Michel Lainé* chief operating officer of its newly formed Offshore Div.

Martin Pugh becomes senior vice president and plastics business president for **Styron** (Berwyn, Pa.). He will be located at the company's European Regional Operating Center in Hogen, Switzerland.

Pump Solutions Group (PSG; Oakbrook Terrace, Ill.), a business unit of Dover Corp., names *Chris Destaso* director of engineering and *Greg Duncan* senior director of business development.

Wolfgang Siegel becomes CEO of **Ter Hell Plastic GmbH** (Herne, Germany).

Rainer Beaujean becomes CFO of **Gerresheimer AG** (Düsseldorf, Germany), a producer of specialty glass and plastic products for pharmaceutical applications, and he joins the company's Management Board. ■

Suzanne Shelley

BUSINESS NEWS

PLANT WATCH

KBR to provide technology package for ammonia/urea plant in Indonesia

February 7, 2013 — KBR (Houston; www.kbr.com) has announced that it was selected by PT Pupuk Sriwidjaja Palembang, to provide licensing, engineering services and proprietary equipment for a new 2,000 metric tons (m.t.) per day ammonia and 2,750-m.t./d urea plant located in Palembang, South Sumatra, Indonesia. The plant will be designed using KBR's Purifier technology. Construction of the grassroots facility is part of a consortium between Rekayasa and Toyo Engineering Corp. Rekayasa will be responsible for the ammonia and Toyo Engineering will be responsible for urea.

Lanxess to build new pigment plant in China

January 28, 2013 — Lanxess AG (Leverkusen, Germany; www.lanxess.com) is investing about €55 million to build a facility for iron-oxide red pigments at the Ningbo Chemical Park on the Chinese East Coast. Production capacity is scheduled for the 1st Q of 2015 with an initial capacity of 25,000 m.t./yr.

Butyric acid debottleneck project will add capacity

January 25, 2013 — Eastman Chemical Co. (Kingsport, Tenn.; www.eastman.com) is planning to debottleneck the butyric acid production capacity at its Kingsport, Tenn. facility. The debottleneck, scheduled for completion in the 4th Q of 2013, will add an additional 11 million pounds of capacity to support growing internal and external demand for the acid.

Linde and Forest BtL sign licensing agreement for Carbo-V technology

January 24, 2013 —Linde Engineering Dresden GmbH, a subsidiary of The Linde Group (Munich, Germany; www.linde.com) has signed an agreement with the Finnish Forest BtL Oy for the licensing of the biomass gasification technology Carbo-V, which will be implemented in a new biomass–to-liquid (BtL) plant in Kemi, Northern Finland. The commercial operation for the production of biodiesel and naphtha is expected to start at the end of 2016. The BtL plant will have a gasification capacity of 480 MW and an output of about 130,000 tons/yr of biodiesel and naphtha, using about 1.5 million tons of wood (For more details about Carbo-V, see *Chem. Eng.*, August 2003, p. 16).

Petronas and Evonik sign LoI for projects in 'Rapid Project'

January 23, 2013 — Petronas (Kuala Lumpur, Malaysia; www.petronas.com.my) and Evonik Industries AG (Essen, Germany; www.evonik.com) have signed a letter of intent (LoI) to jointly embark on the development of production facilities of specialty chemicals within Petronas' Refinery & Petrochemical Integrated Development (Rapid) project in Pengerang, Johor, Malaysia. Under the LoI, the two parties will form a partnership to jointly own, develop, construct and operate facilities for the production of hydrogen peroxide, C4 co-monomer and oxo-products within Rapid. The plants are expected to have the capacity to produce 250,000 m.t./yr of hydrogen peroxide, 220,000 m.t./yr of isononanol and 110,000 m.t./yr of 1-butene. The hydrogen peroxide will be used onsite to produce propylene oxide by the licensed, HPPO process Evonik had jointly developed with ThyssenKrupp Uhde (Dortmund, Germany; www.uhde.eu). These projects are expected to come onstream in 2016.

BASF and Sinopec move toward a world-scale isononanol plant in Maoming

January 22, 2013 — BASF SE (Ludwigshafen, Germany; www.basf.com) and China Petroleum & Chemical Corp. (Sinopec; Beijing) have completed a joint feasibility study and taken the next steps toward establishing a world-scale isononanol (INA) plant in Maoming, Guangdong, China. Under the terms of the feasibility study, a new 50-50 joint venture (JV) will be formed, BASF MPCC Co. Ltd. Pre-approval has been received from the Maoming Administration of Industry and Commerce for the name of the venture. The partners expect to begin production at the new plant around the middle of 2015.

Evonik expands its market position for C4-based products

January 11, 2013 — Evonik Industries AG is further expanding its market lead in C4-based products and investing in the expansion of its production facilities. The Group's 1-butene capacity in Marl (Germany) Chemical Park will be expanded by 75,000 tons. In Antwerp, Belgium, the production of butadiene will be expanded by 100,000 tons, while in Marl and Antwerp, the capacity of MTBE will be increased by 150,000 tons in total. The investment will run into hundreds of millions of euros. The expansions are scheduled to go onstream in 2015.

Teijin Chemicals to establish JV with SK Chemicals

February 5, 2013 —Teijin Chemicals Ltd. (Tokyo, Japan; www.teijin.co.jp) and SK Chemicals, a South Korean chemical producer, plan to establish a JV to develop, produce and distribute polyphenylene sulfide (PPS) resins and compounds. The JV, in which Teijin Chemicals will hold a 34% share and SK Chemicals the remaining 66%, will construct a PPS resin plant in Ulsan, South Korea. The plant will begin operations with a PPS resin production capacity of 12,000 tons/yr starting in April 2015. As demand grows, capacity is expected to reach 20,000 tons.

MERGERS AND ACQUISITIONS

Praxair to acquire beverage-carbonation solutions provider, NuCO2

February 5, 2013 — Praxair, Inc. (Danbury, Conn.; www.praxair.com) has entered into an agreement to acquire NuCO2 Inc. from Aurora Capital Group, a Los Angeles, Calif.-based private equity firm, for $1.1 billion in cash. The transaction is subject to customary conditions to closing, including regulatory approval, and is expected to close by the end of the 1st Q of 2013.

Bechtel acquires Chevron's water treatment process

January 28, 2013 — Bechtel (Houston; www.bechtel.com) has purchased Chevron's Waste Water Treatment (WWT) Process. The WWT Process is a proprietary, two-stage sour-water-stripping process that separates ammonia and hydrogen sulfide streams from sour waters generated by a petroleum refinery's process units. The WWT Process technology is managed by Bechtel Hydrocarbon Technology Solutions, Inc., a wholly owned subsidiary of Bechtel.

JV formed to produce pure carbon dioxide from waste gas in China

January 26, 2013 —The industrial gas specialist, Messer Group GmbH (Bad Soden, Germany; www.messergroup.de) and Sichuan Meifeng, a Chinese chemicals company, have signed a JV agreement to found Sichuan Meifeng Messer Gas Products. The JV will invest some €7.24 million to produce around 100,000 ton/yr of liquid carbon dioxide from industrial CO_2 waste gases. Sichuan Meifeng Messer plans to supply liquid CO_2 starting in mid-2014. ■

Dorothy Lozowski

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

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Economic Indicators

2010 2011 2012 2013

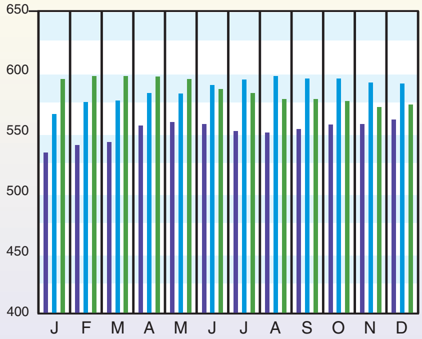
DOWNLOAD THE *CEPCI* TWO WEEKS SOONER AT *WWW.CHE.COM/PCI*

CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957-59 = 100)	Dec.'12 Prelim.	Nov.'12 Final	Dec.'11 Final
***CE* Index**	572.7	570.6	590.1
Equipment	694.5	691.7	718.7
Heat exchangers & tanks	634.8	634.0	681.6
Process machinery	657.9	656.7	670.9
Pipe, valves & fittings	895.8	890.4	902.1
Process instruments	422.5	420.7	428.0
Pumps & compressors	899.6	895.8	910.1
Electrical equipment	511.4	511.2	511.5
Structural supports & misc	734.5	726.0	762.4
Construction labor	321.8	321.6	331.4
Buildings	527.2	525.0	519.1
Engineering & supervision	327.7	327.3	329.6

Annual Index:

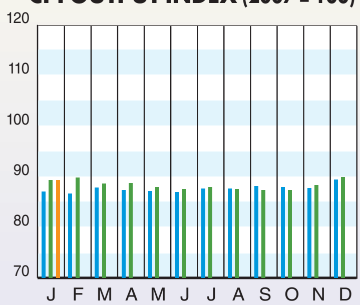
2004 = 444.2
2005 = 468.2
2006 = 499.6
2007 = 525.4
2008 = 575.4
2009 = 521.9
2010 = 550.8
2011 = 585.7



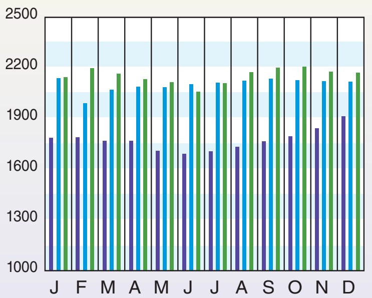
CURRENT BUSINESS INDICATORS

	LATEST		PREVIOUS				YEAR AGO	
CPI output index (2007 = 100)	Jan.'13 =	89.3	Dec.'12 =	89.9	Nov.'12 =	88.3	Jan.'12 =	89.3
CPI value of output, $ billions	Dec.'12 =	2,173.0	Nov.'12 =	2,176.8	Oct.'12 =	2,208.7	Dec.'11 =	2,139.8
CPI operating rate, %	Jan.'13 =	76.9	Dec.'12 =	77.6	Nov.'12 =	76.2	Jan.'12 =	77.2
Producer prices, industrial chemicals (1982 = 100)	Dec.'12 =	300.2	Nov.'12 =	297.3	Oct.'12 =	299.7	Dec.'11 =	304.4
Industrial Production in Manufacturing (2007=100)	Jan.'13 =	95.4	Dec.'12 =	95.8	Nov.'12 =	94.8	Jan.'12 =	93.8
Hourly earnings index, chemical & allied products (1992 = 100)	Jan.'13 =	154.4	Dec.'12 =	153.5	Nov.'12 =	153.9	Jan.'12 =	158.7
Productivity index, chemicals & allied products (1992 = 100)	Jan.'13 =	107.0	Dec.'12 =	107.5	Nov.'12 =	105.8	Jan.'12 =	109.0

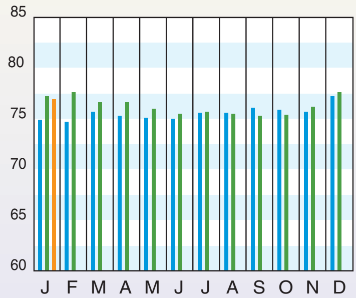
CPI OUTPUT INDEX (2007 = 100)



CPI OUTPUT VALUE ($ BILLIONS)



CPI OPERATING RATE (%)



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

CURRENT TRENDS

Preliminary data from the *CE* Plant Cost Index (CEPCI; top) for December 2012 (the most recent available) indicate that capital equipment prices rose 0.37% from November to December, reversing the dip from the previous month. Even after the rise, the current-year plant cost index stands at 2.95% lower than it was in December of the previous year (2011). Within the CEPCI, the preliminary December numbers indicate that all equipment-class subgroups, as well as construction labor, buildings and engineering and supervision edged upward in December of last year. Meanwhile, the Current Business Indicators from IHS Global Insight (middle), show a slight decrease in the latest CPI output index value (Jan. 2013). ■