# CHEMICAL ENGINEERING

June 2010

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## Editor's Page

# Safety, ethics on the Horizon

Any chemical engineer can attest to the fact that safety is an ongoing pursuit in our profession, where we occasionally find our teams taking two steps forward and then one step back. Foreseeing and avoiding every type of equipment malfunction is practically impossible, and even the most diligent, conscientious and experienced professionals are bound to make mistakes. However, when the insightful warnings of engineers or operators are ignored — particularly by their superiors — labels like malfunction and mistake sound more like negligence and misconduct. Sadly, such unethical head turning continues to be found at the root of many industrial safety incidents, casting a shadow on the remarkable safety progress that we've made over the past several decades.

In that vein, disasters in one industry often serve as lessons or wakeup calls for another. Such is the case in what we know so far about events surrounding the Deepwater Horizon, the mobile offshore-drilling unit owned by Transocean (Houston; www.deepwater.com) and leased by BP (London; www.bp.com), which exploded on April 20th, killing eleven men and spewing staggering volumes of petroleum and natural gas into the Gulf of Mexico. While the official cause of the notorious disaster will be investigated for months to come, allegations of head turning give reason for pause today.

Early interviews and testimonies with the Deepwater Horizon crew allege that safety concerns were ignored by management on more than one occasion leading up to the explosion. The most basic explanation for the inaction is that the team was under pressure to speed up its production schedule, a condition that is likewise common in the chemical process industries (CPI). In fact, here is where we find the paradox: When setpoints are being changed and equipment is being pushed to its limits, process upsets and malfunctions are at their greatest probability; yet so are the chances that an individual will dismiss a warning that should have been investigated. In other words, ethics are more likely to be compromised when safety is also at its most vulnerable point.

That reality is disconcerting enough by itself, but it becomes downright alarming in the context of what has taken place at many CPI companies over the past year. In order to either minimize financial losses or maintain profitability amidst the 2008–2009 recession, most CPI companies reduced staff. Many of those reductions targeted the most experienced engineers and operators, who were already dwindling in supply vis-à-vis retirement. So what we have now is a group of industries on a capacity upswing, being maintained and operated by overstretched — and in many cases under-experienced — people. We do not have to guess what the worst-case effects of this situation might be.

The best case scenario would be that this precarious state of affairs would put the CPI on a heightened state of alert. In that atmosphere, inexperienced engineers and operators would be quick to speak up when they observe something unsettling or find themselves beyond their skill level. In turn, managers would reward those who speak out and be quick to provide guidance where needed. Most importantly, raised safety concerns would not fall flat on a single ear.

Now more than ever, we must all be diligent to voice the risks we observe and take seriously those that are brought before us. Because, if engineers and operators can't speak up for safety and be heard, the consequences will be deafening. ■

*Rebekkah Marshall*

We address these complex issues in our Engineering Ethics Webinar, which will be broadcast live on June 10th at 3:00 p.m. Eastern Time and offered on demand later on (www.che.com/webcasts).

# Letters

## New gasification process?

*April*, A new gasification process moves a step closer to commercialization, p. 11: It would seem IHI is a little behind the times with this process — say about 20 years. Battelle developed and proved this process in the 1980s. Furthermore, DOE and others funded and proved out the process over 15 years ago. In 2004, DOE selected a team to build a 285 MW version of this plant. It was cancelled a couple of years later as being too costly. One wonders too costly compared to what? Cap and Trade!

**Daniel L. Dunn, P.E.**
Northridge, Calif..

*While the idea of coal gasification is not new, the process described in this article is certainly new for IHI, since the company is in the process of demonstrating the technology in Indonesia. — Ed.*

## $CO_2$ and oceanic acidity?

I have a comment on $CO_2$ as an atmospheric pollutant [commenting on the March Editor's Page, "Opinions on GHGs"]. If one subscribes to the concept of evolution and the beginning of life in a primordial slime, then one has to recognize that $CO_2$ is absolutely necessary to life on earth. Something had to supply the carbonaceous matter to the solution to provide amino acids for the first living organisms. Proceeding from there, carbon dioxide provides the carbonaceous material for the growth of all plants and animals. The wonderful reaction between carbon dioxide and water in the presence of chlorophyll and sunlight provides food for all living organisms.

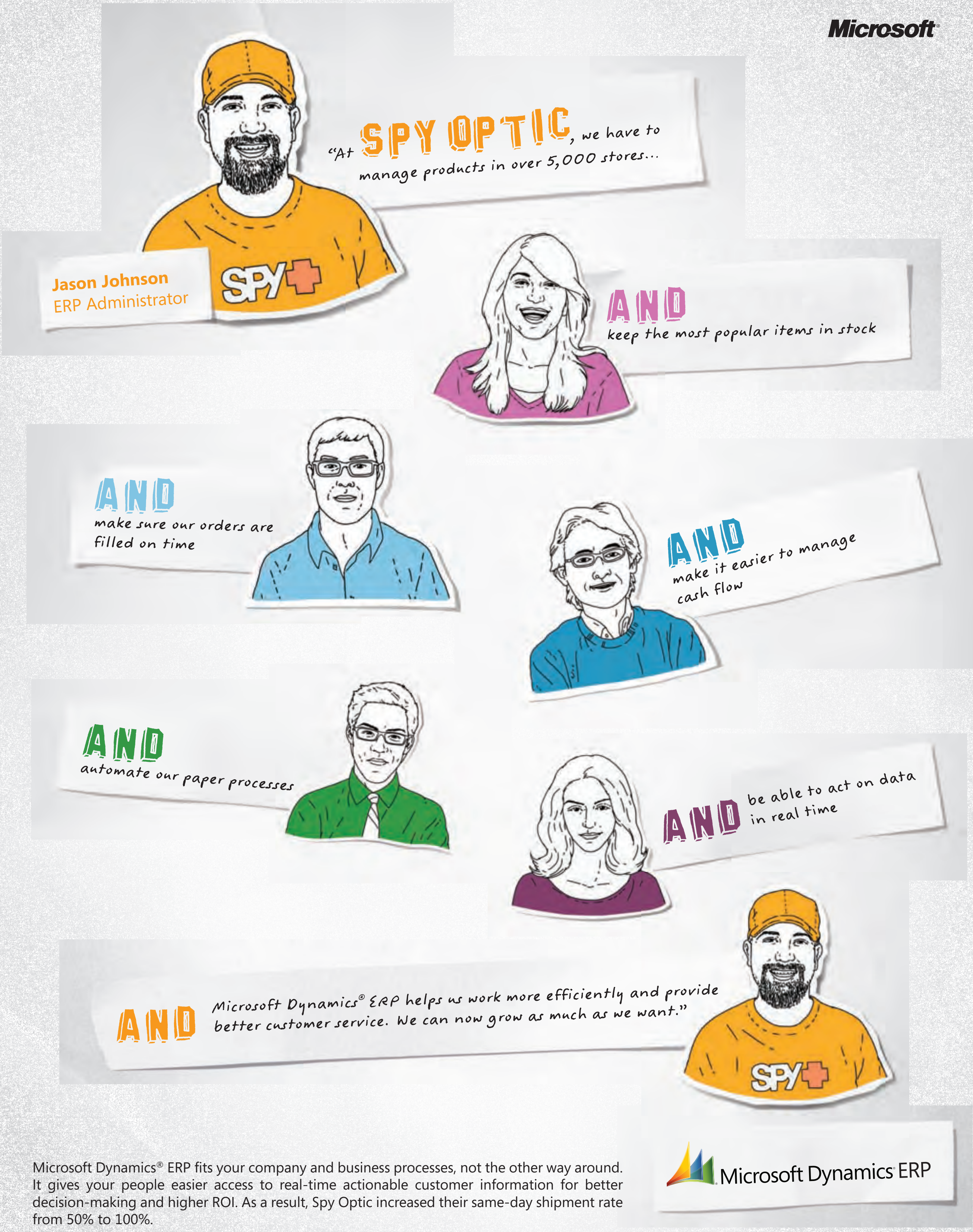
I question whether the small increase in carbon dioxide concentration in the atmosphere will have a great effect on the acidity of our oceans. The ionization constant for the acid $H_2CO_3$ is $4.4 \times 10^{-7}$, yielding a pH of 6.43. I know carbon dioxide in water can and will dissolve calcium carbonate. I have seen such a solution bubble from the ground at Mammoth Hot Spring in Yellow Stone Park. The water flows over the calcium carbonate deposit until it cools; as the $CO_2$ is lost, calcium carbonate crystals deposit. I am sure this process begins at higher temperatures and pressures far beneath the earth's surface. It seems to me that there are numerous other acids available to be dissolved in the oceans that will yield a more acidic solution.

I enjoyed your editorial, and I read your magazine monthly.

**Edward C. Murray**
Valley Forge, Pa

## Postscripts, corrections

*Chemical Engineering* Plant Cost Index (Online database subscription only; www.che.com/pci): In any downloads prior to the week of June 1, 2010, the January 1993 numbers may have contained errors. The problem has been fixed. Our thanks to reader Kristine V. Beese for bringing this to our attention. ■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## NORTH AMERICA

**Hydraulic Institute 2010 Spring Meeting**. Hydraulic Institute (HI; Parsipppany, N.J.). Phone: 973-267-9700; Web: pumps.org
*Fort Worth, Tex.* **June 9–12**

**Recycling Metals from Industrial Waste**. Colorado School of Mines. (Golden, Colo.). Phone: 303-273-3321; Fax: 303-273-3314; Web: outreach.mines.edu/cont_ed/heavy.shtml
*Golden, Colo.* **June 22–24**

**7th International Symposium on Contact Angle, Wettability and Adhesion**. MST Conferences (Hopewell Junction, N.Y.). Phone: 845-897-1654; Web: mstconf.com
*Danbury, Conn.* **June 23–25**

**103rd A&WMA Annual Conference & Exhibition**. Air and Waste Management Assoc. (Pittsburgh, Pa.). Phone: 412-904-6020; Web: awma.org
*Calgary, Alta., Canada* **June 22–25**

**Chemical Sector Security Expo**. Synthetic Organic Chemical Manufacturers Association (Washington, D.C.). Phone: 202-721-4165; Web: socma.org
*Baltimore, Md.* **July 6–8**

**Semicon West 2010**. SEMI North America (San Jose, Calif.). Phone: 408-943-6978; Fax: 408-943-7953; Web: semiconwest.org
*San Francisco, Calif.* **July 13–15**

**IFT 2010 Annual Meeting and Food Expo.** Chicago Institute of Food Technologists (Chicago, Ill.). Phone: 312-782-8424; Web: www.am-fe.ift.org
*Chicago, Ill.* **July 17–20**

**Gordon Research Conference on Green Chemistry**. Gordon Research Conferences (West Kingston, R.I.). Fax: 401-783-7644; Web: grc.org/programs.aspx?year=2010&program=greenchem
*Davidson, N.C.* **July 25–30**

**21st Biennial Conference on Chemical Education**. American Chemical Society (ACS) Division of Chemical Education. (Washington, D.C.). Email: program@bcce2010.org; Web: bcce2010.org/home/home.php
*Denton, Tex.* **August 1–5**

**IWA World Water Congress and Exhibition 2010**. International Water Association (Alexandria, Va.). Phone: +31 703 150 793; Web: iwa-2010montreal.org
*Montreal, Ont., Canada* **Sept. 19–24**

**ChemInnovations 2010 Conference & Expo**. Tradefair Group, Access Intelligence LLC (Houston). Phone: 713-343-1879; Web: cpievent.com
*Houston* **Oct. 19–21**

## EUROPE

**International Conference on Medicinal Chemistry**. LD Organisation (Louvain-al-Neuve, Belgium). Phone: +32-10-454777; Fax: 32-10-459719; Web: ldorganisation.com
*Reims, France* **June 30–July 2**

**Macro 2010: 43rd IUPAC World Polymer Congress**. Royal Society of Chemistry (RSC; London, U.K.). Phone: +44 20 7437-8656; Fax: +44 20 7437-8883; Web: rsc.org/ConferencesAndEvents/RSCConferences/Macro2010
*Glasgow, Scotland* **July 11–16**

**1st International Conference on Materials for Energy 2010**. Dechema Gesellschaft für Chemische Technik und Biotechnologie e.V. (Frankfurt am Main, Germany). Phone: +49 69 7564-201; Web: dechema.de/enmat2010
*Karlsruhe, Germany* **July 4–8**

**5th International Symposium on Bioorganometallic Chemistry**. Ruhr Universität Bochum (Bochum, Germany). Phone: +49-23-4322-4153; Email: isbomc10@rub.de; Web: rub.de/isbomc10
*Bochum, Germany* **July 5–9**

**Japan-U.K. Symposium: Catalysis for a Sustainable World**. RSC (London). Phone: +44 20 7437-8656; Fax: +44 20 7437-8883; Web: rsc.org/ConferencesAndEvents/
*London, U.K.* **July 15–16**

**Analytical Research Forum 2010**. RSC (London). Phone: +44 20 7437-8656; Fax: +44 20 7437-8883; Web: rsc.org/ConferencesAndEvents/RSCConferences/
*Loughborough, U.K.* **July 11–16**

**K 2010: 18th Int'l Trade Fair Plastics and Rubber**. Messe Düsseldorf GmbH (Düsseldorf, Germany). Phone: +49 211 4560-01; Web: k-online.de
*Düsseldorf, Germany* **Oct. 27–Nov. 3**

## ASIA & ELSEWHERE

**19th International Symposium on Plant Lipids**. American Oil Chemists' Society (Urbana, Ill.). Phone: 217-359-2344; Fax: 217-351-8091; Web: aocs.org
*Cairns, Australia* **July 11–16**

**5th Society for Biological Engineering Int'l Conference on Bioengineering and Nanotechnology**. American Insitute of Chemical Engineers (AIChE; New York, N.Y.). Phone: 800-242-4363; Email: secretariat@icbn2010.com; Web: icbn2010.com
*Biopolis, Singapore* **Aug. 1–4**

**CPhI South America**. UBM International Media BV (Maarsen, the Netherlands). Web: cphi-sa.com
*Buenos Aries, Argentina* **Aug. 17–19** ■

*Scott Jenkins*

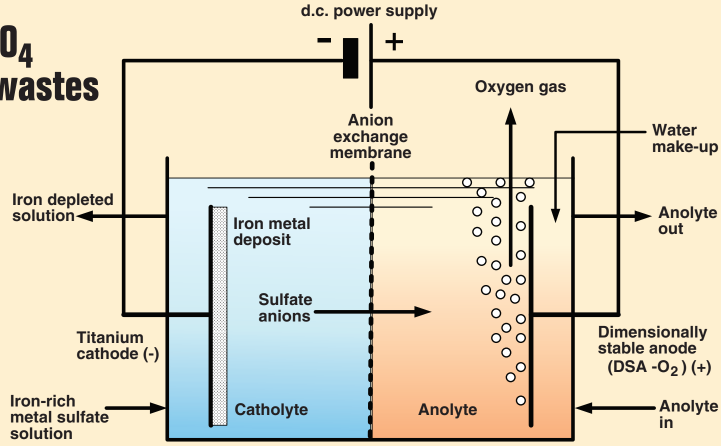
# Chementator

Edited by Gerald Ondrey June 2010

## Electrochemistry regenerates $H_2SO_4$ and recovers iron from industrial wastes

An electrochemical process for recovering sulfuric acid and metallic iron from iron-rich sulfate wastes, such as spent pickling liquors and pregnant leach solutions generated in minerals and metals processing, has been patented by François Cardarelli, an independent researcher located in Montreal, Canada (www.francoiscardarelli.ca). Cardarelli says the process offers a green solution to the processing of these wastes, most of which currently end up in landfills or disposal piles.

In Cardarelli's process, an iron-rich sulfate solution is pH-adjusted to below 3.0 by adding a neutralizing agent, such as sodium hydroxide, and fed to the cathode side of an electrolytic cell (diagram). The adjustment is necessary to avoid the evolution of hydrogen at the cathode, a competing process, says Cardarelli. Iron deposits on the titanium cathode (a material chosen to prevent $H_2$ evolution), while sulfate anions migrate through an ion-exchange membrane to the anode. Initially there is a 10% solution of $H_2SO_4$ on the anode side. Acid removal starts when the $H_2SO_4$ concentration reaches about 30%. Oxygen evolves from the iridium dioxide-coated Ti anode.




$$2Fe^{2+} + 4e^- \rightarrow 2Fe(s) \qquad 2H_2O \rightarrow O_2(g) + 4H^+ + 4e^-$$

$$2FeSO_4 + 2H_2O \rightarrow 2Fe(s) + 2H_2SO_4 + O_2(g)$$

Cardarelli has tested the process, using 1-$ft^2$ electrodes, and is negotiating with potential industrial partners to do pilot tests with units containing about 20 12-$ft^2$ electrodes. No cost figures are available as yet, but Cardarelli says the economics of the process depend on disposal costs, the costs of $H_2SO_4$ and scrap iron, and the utilization of oxygen onsite. He notes that scrap iron currently sells for about $300 per metric ton (m.t.) in the U.S. and up to $450/m.t. in Europe.

## A device to measure density and viscosity non-invasively

Ultimo Measurement (Providence, R.I.; www.ultimompd.com) has developed technology for measuring density and viscosity of process fluids, loose solids and mixtures non-invasively — a percussion-based device that can be mounted on the outside of process tanks, pipes or other vessels. The device strikes a vessel's outside wall, exciting the content material, then senses the resulting vibrations, which are related to the density and viscosity of the content material by a complex combination of physical laws. Proprietary software then analyzes the oscillation data with specialized algorithms that relate the material's oscillation signature with its density or viscosity, explains Ultimo CEO Frank Lubrano. The software is adaptive and self-learning, and can discriminate between valuable and ambient vibrations.

The system's ability to collect information from outside the vessel wall lengthens its service life, since it never contacts the material being measured. Also, the adaptive nature of the striker device and analysis algorithms make the measurement tool effective with virtually all types of liquids, slurries and loose solids, and with any type or size of storage vessels or conduits constructed from a wide range of metals, fiberglass or plastic.

Lubrano points out that his company's device allows processors to obtain early data on viscosity and density, which can reduce plant waste, save resources and improve product quality. He also notes that in field-testing, the device has achieved precision of 0.1% on light powders and 0.5% on polymer materials.

The technology was originally applied as a level measurement tool, but the company has adapted its core technology for density and viscosity analyses. Ultimo has produced prototypes of the measurement devices and is looking to license its proprietary technology to partners.

### An new olefins process

A 40,000-m.t./yr demonstration plant for a new process that produces olefins by catalytic cracking of paraffins-rich naphtha will be started up in October by SK energy (Seoul, South Korea; www.skenergy.com) at Ulsan, South Korea. Developed jointly with KBR (Houston; www.kbr.com), the Advanced Catalytic Olefin (ACO) process uses a proprietary granular zeolite catalyst in a fluidized bed.

The olefins yield is about 65% and the propylene:ethylene ratio is 1:1, versus about 50% and 0.5:1 for naphtha steam crackers, says Tim Challand, president of KBR Technology. The process temperature is about 650°C, compared to about 850°C for a steam cracker. KBR is the exclusive, worldwide licensor of the technology. (For more details on ACO, see *CE*, March 2007, p. 20).

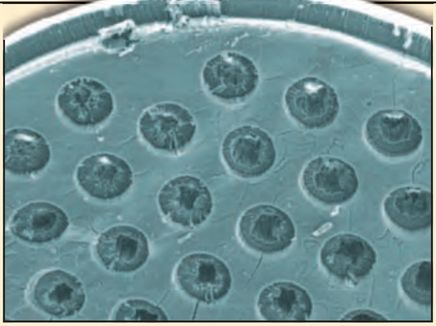
### $LiPF_6$ made in the U.S.A.

Honeywell (Morristown, N.J.; www.honeywell.com) has signed a contract with the U.S. Dept. of Energy (DOE; Washington, D.C.) for a $27.3-million grant to produce high-purity lithium hexafluorophosphate — a conductive salt that is one of four critical

(*Continues on p. 12*)

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

## CNTs show promise as a filter and a catalyst support



Carbon nanotube (CNT) membranes developed by researchers at Rice University (Houston; www.rice.edu) could have applications as nanoparticulate filters, and as nanoscale scaffolds for catalysts. The devices are silicon dioxide wafers with laser-bored holes (~500-µm dia.). The holed wafers are subjected to a chemical-vapor-deposition (CVD) process, during which a "forest" of CNTs grows inside the holes (photo).

The CNTs inside the holes create a matrix through which only nanoscale particles can pass. In testing, the research team, led by Rice engineer Robert Vajtai, was able to remove greater than 99% of sub-micron particles from air. The filters' permeability is affected strongly by the duration of nanotube growth, Vajtai explains.

In a recent paper in the journal *ACS Nano*, the researchers reported functionalizing the nanotubes with catalytic palladium metal to achieve gas-phase heterogeneous catalysis. Using the dehydrogenation reaction of propene to propane as a test system, the activated membranes showed "excellent and durable activity" as a catalytic support, enabling a low activation energy for the propene dehydrogenation reaction of ~27.8 kJ/mol and a turnover rate of 1.1 molecules per Pd site per second.

## An enhanced photocatalyst for making $H_2$ from water

Kazuhiro Sayama and colleagues at the Solar Light Energy Conversion Group at Energy Technology Research Institute, National Institute of Advanced Industrial Science and Technology (AIST; Tsukuba, Japan; unit.aist.go.jp/energy), have developed a cesium-treated tungsten oxide photocatalyst that shows a 19% quantum efficiency at 420 nm, which is 48 times higher compared to existing photocatalysts. The Cs-$WO_3$ photocatalyst is expected to boost the commercial potential for making hydrogen from water in a low-voltage electrolysis process developed at AIST.

The enhanced catalyst is made by surface treatment of $WO_3$ photocatalyst, either by adding a cesium salt to a solution for hydrothermal treatment, or by impregnating the $WO_3$ particles with $Cs_2CO_3$ and sintering at 500°C. Subsequent washing with a strong acid or $FeSO_4$ solution removes excess Cs ions from the $WO_3$ surface, forming ion exchange sites. The catalyst is used as an ion-exchange membrane of an electrolysis cell operating with an aqueous $Fe_2(SO_4)_3$ solution as electrolyte. When the cell is irradiated by light, the $Fe^{+2}$ is oxidized to $Fe^{+3}$ at the catalyst site. This enables the electrolysis of water into $H_2$ to proceed at about half the voltage of a conventional electrolyzer.

## Combined $CO_2$ mitigation and $H_2S$ removal

Last month at the Global Refining Summit (Rotterdam, the Netherlands; May 17–19), Swapsol Corp. (Monmouth Junction, N.J.; www.swapsol.com) introduced a completely new sour-gas-cleanup process that reduces hydrogen sulfide levels below detectable levels (under 4 ppb) while reacting with carbon dioxide to form water, sulfur and a polymer of sulfur and carbon (carsul). Although still in the laboratory stage of development, the process promises to have application in cleaning up landfill gas, sour-gas, fluegas and Claus tailgas, as well as serving as an alternative to Claus technology, says COO Wolf Koch. Swapsol has applied for U.S. and international patents on all aspects of its technology.

Named after its discoverers, the Stenger-Wasas Process (SWAP) involves the reaction of $H_2S$ and $CO_2$ at temperatures of 70–200°C and ambient to moderate pressures. The exothermic reaction is carried out in a catalyst-packed tubular reactor and produces sulfur, water and carsuls. The catalyst is a naturally occurring mineral ore that is pretreated in a manner analogous to common hydrotreating catalysts, says Koch. Sulfur can be recovered from carsul by simply heating it, leaving behind a polymer of carbon that may have applications as a construction material.

Thus far the company has performed the reaction in 1- and 2-in.-dia. tubular reactors, and believes scaleup to a commercial process with a large shell containing multiple tubes is not a problem. Swapsol is now planning to start testing its applications in a pilot plant during the 3rdQ of 2010, and move to the first commercial application — most probably a landfill-gas-cleanup operation — during 2011, says Koch.

(*Continued from p. 11*)

components in rechargeable lithium-ion batteries.

The grant — awarded as part of the American Recovery and Reinvestment Act of 2009 — is intended to help Honeywell become the first domestic supplier of $LiPF_6$. Honeywell has developed a process that produces less waste and a more consistently pure $LiPF_6$ than alternative processes, says the firm.

### Biotech milestone

Last month, DSM Biologics (www.dsmbiologics.com), a business unit of DSM Pharmaceutical Products (Parsippany, N.J.), successfully scaled up its proprietary XD technology from 2 L to 50 L using a CHO (Chinese hamster ovary) line. XD technology dramatically increases the cell density and optimizes the conditions for protein production of a biological culture. The scaleup runs at DSM demonstrated a record level of viable cell densities of up to 170 million cells/mL, and record titer improvements of 5–10 fold over standard fed-batch and perfusion processes have been consistently achieved in multiple mammalian cell systems, including CHO and PER.C6, says the company.

"Companies can now substantially shrink their bioreactor size requirements by 5–10 fold, reducing Capex [capital expenses] required for building a new plant and ultimately reducing overall cost of goods," says Jeremy Caudill, vice president, sales and business development.

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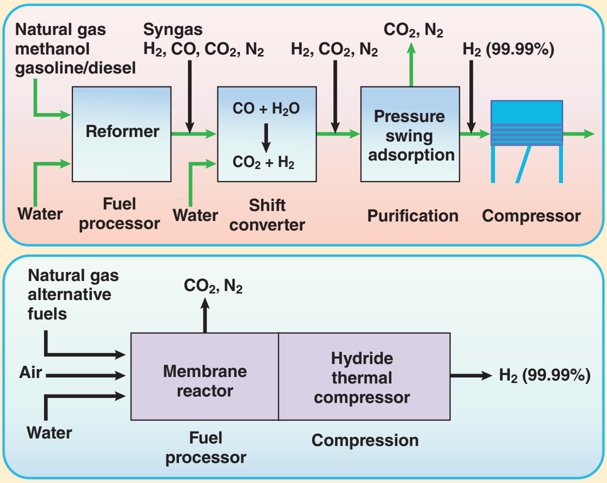
## $H_2$ unit combines production, purification and compression




A recently developed hydrogen generation unit combines an autothermal, fluidized-bed methane reformer with a metal hydride compressor. Aside from combining the reforming, $H_2$ separation and compression, which are part of conventional $H_2$ generation (top diagram), the engineers behind the system demonstrated the use of Pd-alloy membranes in a fluidized-bed environment. The unit is designed to produce $H_2$ outputs of 15 $m^3/h$ (standard temperature and pressure) and has achieved $H_2$ purities of 99.99%.

The system, originally supported under a U.S. Dept. of Energy (DOE; Washington, D.C., www.energy.gov) program, was developed by Membrane Reactor Technologies Ltd. (MRT; Vancouver, B.C., Canada; www.membranereactor.com), along with partners Ergenics Corp. (Ringwood, N.J.; www.ergenics.com) and Linde North America Inc. (Murray Hill, N.J.; www.us.lindegas.com).

MRT developed a steam methane reformer equipped with 25 palladium-alloy membranes that allow *in-situ* separation of $H_2$ generated by the methane reforming reaction (bottom diagram). The Pd alloy membrane selectively allows $H_2$ molecules to diffuse out of the reforming zone through the foil. "The $H_2$ removal actually drives the thermodynamic reaction equilibrium forward," says MRT president Tony Boyd, "so methane conversion rates are high at relatively mild operating conditions" (550°C reactor temperature).

The purified $H_2$ is absorbed into cool metal hydride beds, then desorbed at higher pressure after heating. A series of metal hydride beds can compress $H_2$ from sub-atmospheric pressure to 100 bar in a single system by engineering the hydride composition in each compression stage, Ergenics says.

Boyd envisions the system being used in smaller industrial markets for onsite $H_2$ production, to avoid transporting large numbers of $H_2$ cylinders. In addition, the system could be located at future $H_2$ filling stations that supply fuel-cell automobiles.

The team is working to address remaining technical issues before moving to the design of a commercial prototype, Boyd says.

## Using DME to extract 'green crude' from algae

Algae has recently become an R&D focus for making third-generation biofuels because these oil-containing microorganisms reproduce so quickly and can be grown away from arable farmland. However, getting the oil from the cells — and the water — is energy intensive. Traditionally, the cells are first concentrated into a slurry by compression or centrifugation. Then, the cell walls are broken down by acid hydrolysis or pulverization. Finally, liquid-liquid extraction with an organic solvent (such as hexane or acetone) is used to extract the oil, and the solvent recovered by distillation.

A simpler process, which also promises to be more efficient while consuming less energy, is being developed by Hideki Kanda, chief scientist of the Energy Engineering Research Laboratory, Central Research Institute of Electric Power Industry (CRIEPI, Tokyo, criepi.denken.or.jp/en). The process takes advantage of a unique property of liquefied dimethyl ether (DME) — its miscibility in both oil and (to a lesser extent) water. In the process, liquified DME is continuously circulated through a column containing algae slurry at room temperature and 0.5 MPa pressure. After about 10 minutes, the oil is extracted into the DME. The oil-laden DME can then be phase separated from the water, and the DME recovered as

(*Continues on p. 16*)

### Pt-free fuel cells

Solvay S.A. (Brussels, Belgium; www.solvay.com) has increased its stake in ACAL Energy (Runcorn, U.K.) by investing £1.5 million (€1.75 million). ACAL will use the funds to accelerate the next stage of development of its FlowCath Pt-free cathode technology for fuel-cell systems. This technology uses a proprietary liquid catalyst in the cathode instead of precious metals. Solvay and ACAL are currently preparing to install the world's first demonstration fuel-cell system using FlowCath at Solvay Interox's industrial site at Warrington, U.K. Expected to be operational later this year, the £1.9-million investment will consist of three fuel-cell stacks with an electric power of 5 kW per unit. The units are manufactured by SolviCore, a 50:50 joint venture of Solvay and Umicore (Brussels; www.umicore.com).

### Water-free solar plant

Construction has begun on a solar Brayton-cycle demonstration plant and research facility at CSIRO's National Solar Energy Center (Newcastle, New South Wales, Australia; www.csiro.com). The project is a joint effort of the CSIRO Energy Transformed Flagship and the Australian National University (ANU; Canberra; www.anu.edu.au).

Unlike conventional solar-thermal plants, which concentrate the sun's energy to generate steam for driving a turbine, the Brayton thermodynamic does not use water. Instead, the concentrated solar energy is used to heat compressed air, which then expands through a gas turbine to generate power. Energy to compress the air is obtained from batteries. The Brayton cycle consists of four steps: adiabatic compression, isobaric heating, adiabatic expansion of the heated gas, and isobaric cooling.

The CSIRO system includes 450 heliostats to reflect the sun onto a 30-m-high solar tower, which will power a 200-kW turbine. The plant will be capable of operating at temperatures above 900°C and will be fully operational by March 2011.

**USING DME** (*Continued from p. 14*) vapor by depressurization.

In laboratory trials using blue-green algae (a mixture of microalgae, including the genus *Microcystis*), the DME-based extraction was shown to be 60 times more efficient at extracting oil than traditional methods. The product "green crude oil" was subsequently shown to have a molecular weight of 200–400 and a calorific value of 10,950 cal/g (which is below that of dry wood). The researchers are further optimizing the extraction process with other algae, and plan to scale up the process with commercial partners.

## Forward osmosis moves a step closer to commercialization

Oasys Water Inc. (Cambridge, Mass.; www.oasyswater.com) has commercialized a forward-osmosis (FO) membrane as the next step toward introducing its lower-cost desalination and water-reuse technology. The membrane, developed by Professor Menachem Elimelech, chair of chemical engineering at Yale University (New Haven, Conn.; www.yale.edu), is a polyamide thin-film composite that can be produced on conventional manufacturing lines, says Lisa Sorgini, vice president of markets and strategy at Oasys Water. "The Oasys membrane is roughly 60% thinner than standard reverse-osmosis (RO) membranes thereby reducing resistance to water passage without reducing salt rejection," she says.

As in RO, FO uses a semi-permeable membrane to separate fresh water from dissolved solutes, with the separation driven by an osmotic pressure gradient. In FO, a salt solution of higher concentration draws purified water from the (lower concentration) feed stream through the membrane. Purified water is then obtained by evaporating away the salt of the "draw" solution.

The Oasys Engineered Osmosis (EO) process uses a patented ammonium-carbonate draw solution that, at high concentrations, can provide osmotic pressures in excess of 400 atm making it possible to treat high-salinity feeds that are infeasible for RO, says Sorgini. Unlike RO, which requires high hydraulic pressure to counteract the osmotic pressure and drive separation, EO operates at atmospheric pressure with less expensive materials of construction, she adds. The EO process uses low-temperature (40–50°C) heat to evaporate the draw solutes.

Oasys plans to incorporate full-scale membranes (manufactured by a third party partner) with the patented EO process to produce a system for waters with salinities of 10,000 to over 150,000 mg/L of dissolved solids. Sorgini estimates that the Engineered Osmosis process will be 40–80% more cost effective than traditional seawater reverse-osmosis systems. The first commercial system is scheduled for release in June, 2011.

## Energy efficiency prize for alumina production

At the Hannover Messe 2010, Alumina do Norte do Brasil S.A. (Alunorte; Barcarena, Brazil; www.alunorte.net) and Outotec Oyj (Espoo, Finland; www.outotec.com) received the X Prize (special recognition) for energy efficiency in alumina production. The award, part of the German Energy Agency's (dena; Berlin, Germany; www.dena.de) Initiative EnergieEffizienz, was bestowed to Alunorte for using an energy efficient calcination process developed by Outotec.

To make alumina ($Al_2O_3$), bauxite is first digested in sodium hydroxide, which recovers aluminum as aluminum hydroxide. The $Al(OH)_3$ is then calcined to form $Al_2O_3$.

In the calcination process, $Al(OH)_3$ is first mixed in two preheating stages with the hot waste gas from the calcining stage, predried and partially calcined. The mixture between gas and solid is carried out in a venturi dryer, followed downstream by a cyclone, where gas and solids are separated. The final calcination is performed at 970°C in a circulating fluidized-bed (CFB) reactor. The hot alumina is discharged from the CFB and cooled in a two-stage, fluidized-bed cooler by preheating the combustion air.

Using simulations, Outotec developed a procedure that improves the efficiency of cyclone separation, which considerably reduces the amount of solids remaining in the gas, thereby improving the heat transfer while reducing the pressure losses in the process. Using this procedure, Alunorte has been able to reduce specific energy consumption for calcination from 3,000 kJ/kg to 2,790 kJ/kg — an annual energy saving of about 56-million kWh, and a reduction of $CO_2$ emissions of approximately 18,000 m.t./yr. The €100,000 investment led to a operating-cost reduction of €1,360,000/yr. ■

### Fuel-cell catalyst

Chemists at Brookhaven National Laboratory (Upton, N.Y.; www.bnl.gov) have received three patents for catalysts and their production methods, which have the potential to reduce the amount of platinum needed for fuel cells. Two of the patents were awarded for catalysts that speed up oxygen reduction — one is composed of a thin layer of Pt on palladium nanoparticles; and the other includes metal oxides, such as those of niobium and ruthenium, with a thin layer of Pt on the metal-oxide catalysts. The third patent covers a process for adding gold clusters to Pt-based catalyst, which is said to improve the performance of fuel cells during acceleration. The catalysts and technology are available for licensing.

### Zeptomole detection

The latest triple-quadrapole, LC/MS (liquid-chromatography mass-spectrometer) system from Agilent Technologies Inc. (Salt Lake City, Utah; www.agilent.com) has a 10-fold increase in sensitivity over its predecessors, enabling the instrument to detect molecules at the zeptamole ($10^{-12}$ mol) level. Incorporating iFunnel technology, the system covers a linear dynamic range over six orders of magnitude.

### Washdown motors

At Interphex (New York; April 20–22), Stainless Motors, Inc. (Rio Rancho, N.M.; www.stainlessmotors.com) launched what is claimed to be the first washdown-duty stainless-steel motors approved for use in hazardous locations. The motors are UL-approved for use in Class I, Div. 1, Groups C and D and Class II, Div. 1, Groups F and G environments. They are highly resistant to caustic liquids, vapors and dust, making them suitable for applications requiring safety, cleanliness and wash-down tolerance, says the manufacturer. ❑

Newsfront

# JUST COOL IT!

Air Products

**FIGURE 1.** Cryogenic cooling is suitable for processes such as refrigeration and size reduction. These photos depict equipment using $N_2$ for food processing and particle reduction

## New process cooling technologies make water and capital conservation possible for chemical processors

Like other aspects of chemical processing, cooling operations are being closely examined for ways to reduce costs and resource usage. Whether it's cooling towers or industrial gases, experts say embracing new technologies makes it possible to get more bang for your cooling buck.

### Cooling technologies

Currently, the fleet of cooling towers in the chemical process industries (CPI) is fairly old and a large number of them are approaching the end of their design life, says Paul Lindahl, director of market development with SPX Thermal Equipment and Services (Charlotte, N.C.). "This means the towers now require more frequent inspections and more work to keep them structurally fit, so many owners are evaluating whether or not to replace them," he says.

Though capital is tight, replacing an aging cooling tower with one that conserves water, energy or both, just might make good fiscal sense in resource cost savings, say the experts.

Hybrid cooling towers are a suitable replacement for traditional equipment when the goal is to reduce water and energy consumption. Most traditional cooling towers run water across a fill material and then blow air across it to provide cooled process water, which is both water and energy intensive. Hybrid fluid coolers, on the other hand, employ a design that can provide leaving-water temperatures in ranges similar to temperatures achieved with conventional evaporative cooling tower systems, while reducing energy and water use, cutting operating costs and providing clean water for a process.

Thermal Care (Niles, Ill.) offers Hybrid Fluid Coolers, featuring an adiabatic design, which operate as air-to-water heat exchangers and use a number of variable speed fans as dictated by process cooling requirements, says Tom Benson, vice president of sales and marketing.

During much of the year and in warm weather climates, hybrid coolers can provide 85°F exit water temperatures. In cooler climates, leaving-water temperatures as cool as 46°F are possible without using glycol. And, the units do this while saving big on energy and water consumption. On hot weather days, the relative humidity of ambient air is increased by spraying an atomized fine mist of city water into the incoming air stream on both sides of the unit. The adiabatic system decreases the air temperature as it enters the unit and results in lower exit water temperatures compared to those achieved by a cooling tower alone.

Users can run process water temperatures low enough using only a hybrid fluid cooler so that it might be possible to operate equipment without the use of additional, central-chilling units. And, since the hybrid fluid coolers are closed loop, there is no need to replace evaporated process water, which uses less water for process cooling than a conventional evaporative cooling tower system and conserves water. As a bonus, process water is kept clean and uncontaminated without the need to treat for water scale or bacteria.

Frigel (East Dundee, Ill.) offers a similar piece of equipment, called the Ecodry system, which the company touts as Intelligent Process Cooling — a system that uses ambient air to cool clean process water and offer flexibility.

What makes the Ecodry systems smart begins with a close-circuit fluid cooler, in place of a traditional cooling tower. The water returning from the process is pumped into heat exchangers and cooled with ambient airflow. This process provides clean water at the right temperature to process machines year round.

Ecodry can also be used in conjunction with the company's Microgel (chiller/TCU combo) or Turbogel (TCU) to serve as an alternative to a central chilling system and provide temperature control at each machine. In this case, a single set of uninsulated pipes supplies the process water, without heat gain, to a Microgel or Turbogel on each machine. These units offer high flow, precise temperature control and a built-in free cooling valve that provides automatic free-cooling when ambient temperatures are lower than the process set point. By controlling flow and temperature at the point of use, energy is conserved.

Another method of reducing cooling-

## A LOOK AT R22 REPLACEMENTS

The U.S., among other countries, has passed laws that mandate commercial facilities to phase out usage of the refrigerant R22 by 2015. Used extensively throughout the world in HVAC systems, process chillers and industrial refrigerant plants, R22 contains hydrochlorofluorocarbons, which are reputed to damage the ozone layer and contribute to global warming.

The ban prohibits R22 refrigerant usage in various areas of production, in household equipment and in certain kinds of vehicles. New refrigeration and air conditioning equipment being manufactured can no longer contain the chemical. Bans on new R22 refrigerant in the maintenance and servicing of existing refrigeration and air conditioning systems takes place this year, while the use of recycled R22 for the same purposes will be prohibited by 2015.

As the refrigerant is phased out, alternative substances have been made available. However, R22 replacement "is not a trivial process," says Gus Rolotti, director of technical sales and services with Arkema Inc. (Philadelphia, Pa.). R22 retrofits necessitate modifying existing heating and cooling/refrigeration systems to accommodate the replacement, and doing so with minimal process interruption. He adds that because an existing refrigeration system is already designed for use specifically with R22, it is likely that users will lose some capacity when replacing the refrigerant. "Something has to give," he says. "If a system is already at the limits of its capacity, maybe retrofitting with a new refrigerant is not the right option."

However, if retrofitting appears to be a feasible solution, there are many alternatives to choose from. Arkema offers several in its Forane line of refrigerants. The company says Forane 427A is an effective replacement for R22 in a variety of temperature-critical refrigeration and air conditioning applications. As a matter of fact, recently completed R22 retrofit installations using 427A have demonstrated overall system performance comparable to R22, says the company. In addition, no adjustments or change-outs to the expansion valves or other major components were required during any of the retrofit operations.

One of the retrofits was undertaken in a high-temperature refrigeration baby-food preparation room at La Mere Poule (Saint-Leonard, Quebec, Canada). Previously, the room was cooled by an R22 refrigeration system, using a semi-hermetic, reciprocating compressor with a rooftop-mounted condenser and a ceiling-mounted evaporator assembly. A change of the compressor oil to POE (polyolester oil), replacement of the system filters, and deep evacuation were performed. No changes in settings were required for the expansion valves, pressure controls or other system components.

According to La Mere Poule, overall system performance was nearly indistinguishable from the system's prior performance with R22. Operating pressures with Forane 427A were close to those measured for R22 and compressor discharge temperatures and amperage draw were both lower.

Jon Edmonds, president of Edmonds Engineering Co.,(Birmingham, Ala.) suggests that natural refrigerants may once again be gaining popularity as replacements for R22 in the chemical processing and industries. "Ammonia, carbon dioxide and, to a lesser degree, propane have renewed interest in industry for use as refrigerants."

Sometimes referred to as R717, ammonia or $NH_3$, anhydrous ammonia is commonly found in industrial refrigeration. Ammonia has the advantage of high latent heat and excellent heat transfer properties and is readily available at an economical cost when compared to other commercial refrigerants. From an environmental standpoint, ammonia has no ozone depletion or global warming potential and is biodegradable.

Carbon dioxide, also known as $CO_2$ or R744, is undergoing resurgence for use in low-temperature applications. While its use as a refrigerant does not contribute to greenhouse gas problems, it is considered a high-pressure refrigerant. A $CO_2$ refrigeration system that experiences an emergency shutdown or power outage may require measures to contain the refrigerant.

Propane is commonly found in large chemical and refining facilities. As a highly flammable gas, however, its use is restricted to facilities where requirements of specific area classifications, such as explosion-proof electrical devices, are required.

Edmonds says that while natural refrigerants are making a comeback, in chemical applications where safety is a hot button issue, a piggyback system might be in order. This type of set up consists of ammonia as the primary refrigerant, located in the safe environment of a protected room where it would condense and cool the $CO_2$, which would then circulate to remote users.

"This is done to prevent the ammonia from circulating out. If $CO_2$ gets loose, it is still an issue, but not as large and dangerous of an issue as an ammonia leak," explains Edmonds.

Rolotti reminds readers that if faced with phasing out R22 or selecting a refrigerant for a new system, the choice should be based on the actual requirements of the cooling process, such as what temperature range is needed, the equipment available for the specific application and the capacity of the system, including the difference between winter and summer conditions. Additional criteria may include safety considerations, familiarity of the chosen refrigerant and ease of integration into existing infrastructure. ❑

tower water usage is through reducing water plume, the cloud of water vapor produced by a cooling tower when warm, moist air is cooled by the ambient air. The SPX ClearSky Plume-Abatement System (Figure 2) is another approach to hybrid cooling towers that focuses on reducing cooling plumes. The bonus here is that it can be installed into existing cooling tower applications, negating the need for complete system replacement.

According to Lindahl, instead of having an air-cooled heat exchanger on top of the wet tower and sharing the same fan, this system has an air-to-air heat exchanger above the wet section. It takes warm air from the wet section and pulls outside air across the other side of the heat exchanger and warms it up before it goes into the tower, which reduces the amount of relative humidity in the air leaving the tower so it doesn't make a visible plume.

"This system is also helpful for chemical processors faced with zero site discharge requirements," explains Lindahl. "Because you're cooling air that leaves the wet section using outside air, there's a lot of water that's condensed in that heat exchanger. That water can be allowed to fall back into the tower to reduce the amount of makeup water that's required to operate the tower."

In addition, he says, that clean water steam can be extracted and used to dilute wastewater streams or to improve the quality of plant water. "This is beneficial to people trying to stretch the water budget in the plant," notes Lindahl.

And for applications such as fluid loop cooling, direct vapor condensing, hydrocarbon desuperheating and sub-

### PROCESS COOLING SERVICE PROVIDERS

| | |
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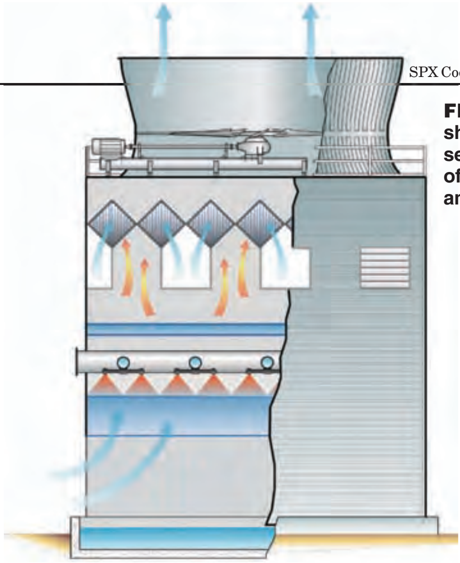

SPX Cooling Technologies

**FIGURE 2.** **Instead of having an air-cooled heat exchanger on top of the wet tower and sharing the same fan, the ClearSky system has an air-to-air heat exchanger above the wet section. It takes warm air from the wet section and pulls outside air across the other side of the heat exchanger and warms it up before it goes into the tower, which reduces the amount of relative humidity in the air leaving the tower so it doesn't make a visible plume**

cooling, Niagara Blower offers a Wet Surface Air Cooler (WSAC) technology (Figure 3) that may help reduce the amount of water required in a plant due to the ability to use low-quality water as spray makeup. Commonly used for adding capacity in "thermally challenged" plants, WSAC coolers and condensers offer additional direct cooling without having additional tower capacity or makeup water.

The basic principle of WSAC technology is that heat is rejected by means of latent (evaporative) heat transfer. Warm process fluids or vapors are cooled in a closed-loop tube bundle. Open-loop water is sprayed, and air is induced over the tube bundle, resulting in the cooling effect. The process fluid being cooled never comes in contact with the environment. Due to the closed-loop design, spray water never contaminates the process stream, and higher cycles of concentration can be achieved.

## Industrial gas tactics

As more facilities are looking to increase cooling capacity without complete replacement of a process cooling system or major capital costs, industrial gases may provide a competitive solution.

"For processors who are looking to boost capacity of mechanical refrigeration systems, or overcome refrigeration shortfalls, liquid cooling-nitrogen systems can be used either by introducing the nitrogen in direct contact with a refrigerant or through a secondary heat-transfer fluid, heat exchanger and circulating pump," says Marna Schmidt, industry manager of industrial cryogenics, with Air Products (Allentown, Pa.).

The benefit here, she says, is the ability to provide a large amount of cooling quickly, with lower upfront costs than installing a new mechanical system and more flexibility for the future. While this "bolt-on" method won't work efficiently for large refrigeration capacities, it is a solid, economic solution for smaller processes such as reaction cooling or size reduction (Figure 1). For example in reaction cooling, a water cooled system or heat transfer fluid might traditionally be used, but liquid nitrogen can be incorporated to provide necessary cooling and temperature control for lower temperature operations, greater flexibility and, where strongly exothermic reactions are used, it can help maintain a stable temperature and aid in difficult reactions.

"It's a boost that will help with what they are trying to do today, in that liquid nitrogen can cool an intermediate heat transfer fluid in a flexible way," explains Schmidt. "Users will acquire fast cool times using only the liquid nitrogen that's required, based entirely on the refrigeration load needed for that reaction."

Source: Niagara Blower

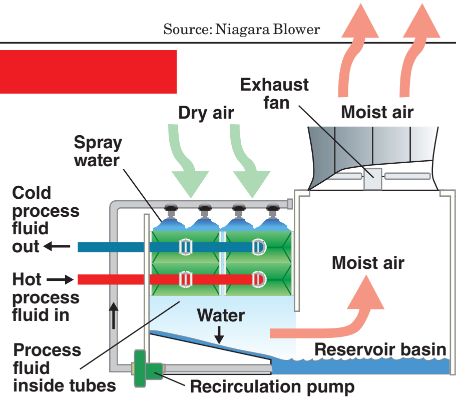


**FIGURE 3. The basic principle of Niagara's WSAC technology is that heat is rejected by means of latent (evaporative) heat transfer. This illustration demonstrates how it works**

In size reduction processes, heat is generated by the friction necessary to crush the material. Not only can the material being processed suffer in quality due to the creation of heat, but it also wastes electricity when 99% of the electrical energy is being converted into heat and only 1% is converted into crushing energy.

In cases like this, liquid nitrogen can be introduced into the mill with the product that's being reduced to provide partial cooling and remove the heat generated by the milling system. "This allows more energy to be focused on the size reduction process and assists in getting smaller particles in cases where heat generation may agglomerate particles," says Schmidt. Better still is that liquid nitrogen can be used only when needed based on external temperature and climate conditions (think summer months when the outside ambient temperatures are higher).

However, processors have to consider whether industrial gases will work for their needs. "Processors still have to look at the application and balance fixed and variable costs," says Schmidt. "The trade off lies in the high capital investment and fixed costs over the lifetime of newly purchased mechanical equipment, and those same cost areas for liquid nitrogen, which has lower upfront costs, but a running variable cost based on how much liquid nitrogen will be needed over a lifetime. If nitrogen can be reused elsewhere in the process, then the economics become more favorable."

Still, she says, an innovative technology may exist for a particular need as industrial gas providers strive to take what is learned in one industry and apply it to another. "We look at it as cross fertilization of industries," says Schmidt. "The solutions we provide in one industry can often be taken into another industry to solve a similar problem." ■

*Joy LePree*



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Pepperl + Fuchs



# KEEPING CORROSION AT BAY

## Today's user friendly, proactive corrosion-monitoring systems provide process engineers with realtime information, helping to avoid failures and reduce costs

P+F's CorrTran MV is designed to take corrosion monitoring out of the laboratory and into every day process control because unlike corrosion coupons, which establish a historical average corrosion rate over time, CorrTran MV can monitor corrosion online and in realtime

Given the recent focus on cost control, it's likely that chemical processors will suffer sticker shock when they learn that industry spends $276 billion annually on corrosion prevention, monitoring and repair. Even more abrasive is the fact that this figure does not include the cost of downtime or accidents resulting from corrosion damage. However, as capital spending allowances continue to come under tighter scrutiny, asset management and sustainability become crucial, and installing the right corrosion monitoring system can help bolster these efforts, while actually controlling corrosion prevention, monitoring and repair costs.

As the economy is slow to rebound, there are two key phrases in the chemical process industries (CPI): asset management and sustainability, notes Michael McElroy, business development manager with Pepperl + Fuchs (P+F; Twinsburg, Ohio). "People are paying more attention to anything related to reliability and sustainability, especially when it concerns safety and environmental discharges. And, all of these hot-button topics are affected by corrosion," he says. "To ensure both proper management of assets and sustainability of equipment, processors must know the condition of their piping, tanks, valves, pumps and other assets. They must know when they need maintenance to avoid shutdowns or accidents. And, corrosion monitoring is an integral part of these focus areas."

Corrosion monitoring perks are many. They range from high-value benefits (such as accident and shutdown avoidance) to mid-range value advantages (including optimizing the life of equipment by not having extensive wear) to lower-range, but still significant, value that stems from knowing when and what kinds of maintenance are actually needed based on knowledgeable predictions (instead of replacing parts on a time-based schedule) to recognizing and maintaining the sweet spot of corrosion inhibiting chemicals.

But how can the "right" corrosion monitoring system actually help reduce the cost of corrosion monitoring itself? According to P+F, corrosion prevention, monitoring and repair costs are better controlled when corrosion is viewed as a process variable, rather than as a purely historical value or in a complex, scientific method.

And the key to this lies in user-friendly monitoring that provides proactive, realtime data that can be analyzed and used by process engineers.

### Proactive, realtime monitoring

One such instrument is P+F's CorrTran MV, which affords greater insight to the process engineer. This two-wire, multivariable, 4–20-mA HART transmitter evaluates general and localized (pitting) corrosion, as well as conductivity, in realtime. It is designed to take corrosion monitoring out of the laboratory and into every day process control because unlike corrosion coupons, which establish a historical average corrosion rate over time, CorrTran MV can monitor corrosion online and in realtime.

Via integration into a new or legacy system, the tool gives plant operators the ability to monitor corrosion rates within their existing software and control system like any other process variable, while the HART signal allows multivariable monitoring of general corrosion, localized corrosion and conductivity.

According to Mike Mendicino, product manager with P+F, this type of monitoring provides many benefits over traditional methods. "Coupons provide only two data points — the mass before you put it into the process and the mass after it corrodes. These limited data give you a corrosion rate, but no knowledge of what happened between," he says.

"With automated methods, users get near immediate notification that something has happened to cause corrosion, right now," he explains. "Engineers can look at the process and know the temperature is increasing or the pH is off. This gives them the power to relate corrosion to events that take place during the actual process and permits engineers to determine and correct whatever process upsets are affecting corrosion."

Similar realtime, online corrosion monitoring is also available in wireless systems for remote locations, such as refineries and tank farms. Honeywell Process Solutions' (Morristown, N.J.) SmartCET is a self-contained, battery-operated, wireless corrosion transmitter. Users install the transmitter in the field and hook it up to the corrosion monitoring probe, which is placed in the process. This probe-transmitter combination communicates a signal to the home base unit, called a Multinode, which receives the wireless signal. The data can be uploaded directly into the plant control system, allowing variables to be trended and alarmed, in the same way as other process variables like temperature and flowrate. For corrosion and material specialists, further statistical data are available automatically from the system, providing trendable corrosion mechanism information.

"This is a very cost effective solution for processing facilities with remote locations or tank farms because it does not require the expense of running wires," says Phillip Ng, global senior product manager of corrosion with Honeywell. "And, the transmitters provide very dynamic data, which can be read every 30 seconds."

He says while some may scoff at this because they believe corrosion is a slow process, the timely, dynamic data allow operators to pinpoint the times when corrosion activity starts spiking. "Since engineers can see what change in the process is causing corrosion spikes, they don't need a corrosion specialist to translate the data," he explains. "They don't need to understand fundamental corrosion science and theory, but simply what process change has taken place and how to react to that change to stop the corrosion from happening."

Honeywell

**Honeywell's XYR 6000 Wireless SmartCET Corrosion Monitoring Transmitter accurately measures corrosion rate and pitting without the expense or hassle of installing cabling**

James Gray, divisional president with Metal Samples Corrosion Monitoring Systems division of Alabama Specialty Products (Munford, Ala.), agrees that this type of data from remote locations is crucial. His company offers a remote telemetry system that obtains realtime corrosion monitoring data via the Internet from anywhere in the world. The system features communications via Inmarsat Isat M2M satellite to a secure Web Monitor data server.

The system is available for use with corrosion monitors based on electrical resistance, linear-polarization resistance or sand (erosion) probes (see box on p. 22). A small optional solar panel connects to the base station for use where no power is available.

"This technology allows remote locations to enjoy the same benefits of realtime data," says Gray. "Because users can now take readings at these remote locations at whatever frequency they want, they can graph out corrosion rate data, allowing them to profile the actual corrosion rate at shorter time intervals than would be possible with traditional methods."

A similar, but non-invasive corrosion monitoring technology is available from GE Energy (Greensville, S.C.) for installation where the integrity of piping, vessels and other fixed assets was historically subjected to time-based manual inspection methods requiring excavation, scaffolding and special permits. GE's Rightrax system reduces these problems via online technology that provides improved, more timely and more frequent corrosion/erosion information, helping to decrease the risk of asset failure. The system uses

## CORROSION MONITORING TECHNIQUES

There are several methods of monitoring corrosion, which can be broken down into two main categories: traditional and automated corrosion monitoring techniques. Within each of these categories, there are a variety of methods. The most popular are defined here by Pepperl + Fuchs.

### Traditional

Traditional corrosion monitoring techniques include the following:

- **Mass loss:** Often referred to as coupons, mass loss methods incorporate inserting pieces of metal directly into the process. Coupons are weighed before insertion and after extraction. Typically, after 90 days they are again weighed and studied to determine the corrosion rate and type
- **Resistance measurement:** Similar to coupon measurement, resistance measurements use wires that are exposed to the process. Resistance is measured and, as the wires corrode, resistance increases, providing an indication that corrosion is occurring
- **Polarization resistance:** This technique measures the inhibition of the corrosion process. This measurement is inversely proportional to the corrosion current
- **Acoustic emission:** Different types of corrosion emit different sounds. These sounds are recorded and provide information about the process relative to corrosion
- **Ultrasonic examinations:** As corrosion occurs, the wall thickness of pipe deteriorates. Ultrasonic examination of the pipe can determine the remaining wall thickness. This calculation is based on the time it takes for non-audible acoustic waves to travel back and forth

### Automated methods

Automated corrosion monitoring techniques include:

- **Linear polarization (LPR):** This technique involves the measurement of the polarization resistance of a corroding electrode to determine the corrosion current. Since the voltage-current response of a corroding element tends to be linear over a small range, determination of the polarization resistance allows the corrosion current to be determined. The slope of the response, the polarization resistance, is inversely proportional to the corrosion current, allowing a corrosion rate to be calculated
- **Harmonic distortion analysis (HDA):** HDA measures the resistance of the corrosive solution by applying a low frequency sine wave to the measurement current. Using harmonic analysis, the solution resistance is determined and combined with the polarization resistance of the LPR method to calculate a more-accurate general-corrosion rate
- **Electrochemical noise (ECN):** This method evaluates the fluctuation in current and voltage noise generated at the corroding metal-solution interface. This technique is generally used to detect non-uniform or localized corrosion.

While some experts suggest that in this limited economy spending on corrosion monitoring is currently down because it is not an absolute necessity when it comes to getting process to the barrel or to the customer, ignoring the practice is not advisable. "Deciding not to monitor corrosion is like deciding not to maintain a car," says James Gray, divisional president of Metal Samples Corrosion Monitoring Systems division of Alabama Specialty Products. "If money is tight, you have to buy gas to make the car go, but you don't have to change the oil, but you know that sooner or later this is going to become an expensive problem. That's what happens with corrosion monitoring if you chose not to do it. Due to a lack of corrosion monitoring, a pipe will become too thin and an accident will occur and someone will get hurt or something will be released to the environment."

To avoid this worst-case scenario, Gray advises selecting the best corrosion monitoring technique within your budget. "Using coupons is better than using nothing at all if you can't afford a more proactive system, because by using nothing at all, you're just prolonging the inevitable," warns Gray. ❑

ultrasonic sensing technology that attaches to the outside of the asset and measures wall thickness. Rightrax sensors can be polled periodically, allowing users to assess not only the useful life by comparing current values to minimum thickness limits, but to establish historical trends.

This ability to trend data provides several benefits. First users can understand the rate at which corrosion/erosion is progressing, allowing better maintenance planning. Second, users can correlate data with process data, providing insight into cause and effect relationships that can help operators understand and avoid conditions that accelerate corrosion/erosion rates and asset degradation.

Integration provides users with the ability to display, trend, analyze, plot and correlate data. Software also permits import/export functionality for integration with reporting tools and programs, as well as automation capability that can automatically analyze data using user-written rules and embedded knowledge. When specific conditions or anomalies of an unknown origin are detected, the system can send advisories to personnel who can then take immediate action to control the situation.

### Specialized applications

Fortunately, proactive analysis of corrosion data is not limited to the pipes and tanks within chemical processing facilities. Nalco Energy Services (Sugarland, Tex.) offers a pre-boiler corrosion-control strategy called NCSM technology. The company's 3D Trasar boiler technology, using the NCSM minimizes boiler feedwater corrosion by measuring the net oxidation/reduction potential (ORP) as a voltage reading of the bulk feedwater at the actual boiler operating temperatures and pressures. NCSM technology detects changes in oxidation/reduction stress and responds in realtime by changing oxygen scavenger or metal passivator feed to maintain the ideal ORP setpoint.

This technology makes it possible to detect and react to the conditions inside the boiler system under actual operating temperatures and pressures. This is a significant leap in technology, according to Maureen Gerty, global industry development manager with Nalco, who says previously samples had to be cooled, which did not provide the same type of response as measuring at-temperature ORP. "When you can take these measurements at temperature, you are actually measuring the real corrosion stress potential, which is far more sensitive than a measurement that's been cooled," Gerty explains. "This allows users to capture all the potential stresses involved and because this information is part of the 3D Trasar boiler technology platform, it can be incorporated with all propriety dashboards, notifications and alarms, so realtime visibility is possible."

This realtime capability can be programmed to notify key personnel and automatically respond by pushing more of certain chemicals or cutting back on them.

And for cleanrooms or other processes that require air monitoring, Purafil's OnGuard 3000 Atmospheric Corrosion Monitor is an electronic instrument that provides realtime readings of an environment's corrosive reactivity level. The OnGuard 3000 also provides realtime temperature and relative humidity readings, which affect the rate of corrosion. By using OnGuard 3000 along with a control system, users may take preventive action before corrosion damage leads to repairs and production shutdown.

Kevin Wilson, technical services engineer with Purafil, says when the tool is tied into a control system, it is possible to automatically bump up the amount of air or pressure being pumped into the room when the measured interval of corrosion climbs too high.

"With today's RoHS (Restriction of Hazardous Substances Directive) instruments, the traces on circuit boards and instruments are more susceptible to more kinds of corrosion than the traditional lead traces. This kind of realtime knowledge provides the power necessary to keep a room at optimal conditions and avoid frequent replacement of expensive electronic equipment or unplanned downtime caused by loss of that equipment." ■

*Joy LePree*

**CORROSION MONITORING SERVICE PROVIDERS**

| | |
|---|---|
| GE Energy | www.gepower.com |
| Honeywell | www.honeywell.com |
| Metal Samples Corrosion Monitoring Systems | www.alspi.com/ms.htm |
| Nalco Energy Services | www.nalco.com |
| Pepperl + Fuchs | www.pepperl-fuchs.com |
| Purafil | www.purafil.com |

Purafil


**Purafil's OnGuard 3000 Atmospheric Corrosion Monitor is an electronic instrument that provides realtime readings of an environment's corrosive reactivity level**



## WHO'S WHO


Bonnett


Van Winter


Scoffin


Funchess


Forslund

*Walter Bonnett* becomes vice-president of PSG marketing for Dover Corp.'s **Pump Solutions Group** (PSG; Redlands, Calif.).

*Christopher Pappas* becomes president and CEO of **Styron**, a chemicals and plastics firm that was recently divested from Dow Chemical Co. to become a privately held company.

**Toray Plastics America** (North Kingstown, R.I.) names *Scott Van Winter* vice-president/general manager of the Lumirror Polyester Film Div., and *Gianfranco Chicarella* product manager for the Torayfan Div.

*Rob Scoffin* is named CEO of software developer Cresset Group Ltd. (Welwyn Garden City, U.K.).

**EagleBurgmann** (Houston), maker of mechanical seals and related systems, names *Van Funchess* OEM/EPC project sales.

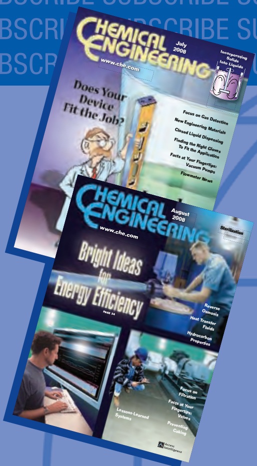
*Steve Braig* becomes president and CEO of **Trexel, Inc.** (Woburn, Mass.), supplier of MuCell microcellular foaming technology for thermoplastics-processing systems.

*Hans Liao* becomes director of metabolic engineering for **OPX Biotechnologies** (Boulder, Colo.).

**Colfax Corp.** (Richmond, Va.), a maker of fluid-handling solutions, names *Arne Forslund* to the newly created position of senior vice-president Europe, Middle East, Africa and Asia. He is also CEO of Colfax pump subsidiary Allweiler AG. ■

*Suzanne Shelley*





# Propelling distillation research

I have 70 supervisors. It sometimes feels like I am pulled in 70 different directions — north, south, east, west, up, down and inside-out. But even after two years at this job, I can still hold my hand steady — if I put it in a vice. Nevertheless, I feel that I have the best job in the distillation world; I am technical director at Fractionation Research, Inc. (FRI; Stillwater, Okla.; www.fri.org).

FRI is a consortium of 70 companies that pool portions of their annual distillation research budgets to collectively perform distillation research. My 70 supervisors are 70 distillation experts from 70 global companies, which include petroleum refiners, chemical companies, engineering companies and vendors of distillation equipment, particularly trays and packing. Each of those companies seems to have different distillation needs and focuses, from thermodynamics to intensification, from crude columns to beer columns, from tray development to packing troubleshooting, and so on.

The bulk of FRI's research budget is spent in Stillwater, Okla., where the membership owns two large distillation columns. The low pressure column is operated at pressures ranging from 10 mmHg to 165 psia (11.4 bara). The lower section is 4 ft (1.22 m) dia.; the upper section is 8 ft (2.44 m) dia. The high-pressure column is operated at pressures up to 500 psia (34.5 bara). In those two research columns, thirteen different binary systems have been used to study the hydraulics and efficiencies of trays and packings. Both columns are about 80 ft (24 m) tall and both have windows. These windows often reveal important insight that would otherwise be overlooked. For instance, if you have ever looked into a deisobutanizer operating near the critical point, you would swear that you were seeing liquid-liquid extraction.

FRI's research directions come from the Technical Advisory Committee (TAC), which holds two meetings each year. Since FRI's membership is very global, one meeting each year is held in the U.S., while the other meeting rotates between Europe (during even years) and the Far East (during odd years).

Each of the 70 member companies assigns an engineer to the TAC. At every FRI TAC meeting, approximately 75% of the time is devoted to reviews of research results of the last six months. Then, projects for the next six months are discussed and voted upon. Meetings are led by Paul Steacy, the TAC chairman, and UOP's distillation "ace."

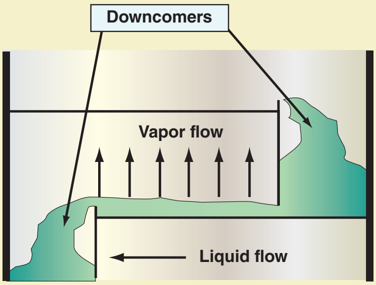
In Oklahoma, approximately 20 people are employed by FRI — the president, the technical director, four Ph.D. engineers, eight technicians and administrative personnel. Working together they produce data, correlations and reports. FRI's ultimate product is DRP, the Device Rating Program. That program is used globally to rate trayed and packed columns.

When the Oklahoma engineers and technicians ask if my instructions are coming from me or my 70 bosses, my typical retort is "We are one and the same." Distillation lovers often exhibit an uncanny ability to reach consensuses. For us, the only worthy direction is forward. That is FRI's direction and the direction in which I hope to propel readers of this column over the coming months. ■

*Mike Resetarits*
*resetarits@fri.org*

# Distillation Tray Design

In a distillation column tray, vapor passes upward through liquid that is flowing across a horizontal perforated plate. Vapor passing through the perforated plate forms a two-phase mixture with the liquid and enables mass transfer contacting. This mixture is typically quite turbulent. Tray design must allow the turbulent liquid to fall away from the rising vapor in the space above the tray, while also enabling the vapor bubbles to rise out of the falling liquid in the downcomer. The downcomer is usually a vertical plate that enables the already contacted froth to travel down to the next tray without remixing with the up-flowing vapor from the tray below.

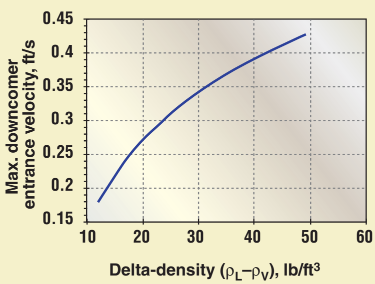



**Side view of a simple tray arrangement**

Generally, designing a column tray entails determining the minimum downcomer area that still allows vapor bubbles to rise through the liquid, selecting the number of downcomers, determining the active area, and checking the flow path length to see if a person can pass through a tray manway. These factors are the primary drivers for determining overall tower size.

Downcomer area is determined by the maximum recommended downcomer velocity. Divide the volumetric flow of liquid by the downcomer velocity to obtain the downcomer top area. Typically a curve of maximum downcomer velocity versus the density difference between liquid and vapor is consulted during this process.

**Maximum downcomer velocity guideline**




A downcomer is generally straight unless its area exceeds 8% of the tower area. In that case, the downcomer is sloped such that its bottom area is 60% of its top area.

## Active area

The active area of a distillation tower is where the vapor contacts the liquid to effect mass transfer. Above the active area, where the liquid falls away from the rising vapor, is the volume where the vapor can expand. Typically, the active area is calculated to be the tower cross-sectional area minus the downcomer top and downcomer bottom area.

The minimum active area ($ft^2$) for normal valve trays can be determined from the following relationship, which is a modification of a commonly used correlation [1] taken at 82% of jet flood:

$$\text{Active area} = \text{V-Load} / [TS^{0.5}(0.0762 - 0.00092(\rho V_2)) - 0.011 W_l]$$

Where,
$\text{V-Load} = CFS_V\,(\rho V / (\rho L - \rho V))^{0.5}$
$TS$ = Tray spacing, in.
$\rho V$ = Vapor density, $lb/ft^3$
$W_L$ = Weir loading, gal/min per in.
$CFS_V$ = Vapor volumetric flow, $ft^3/s$

The required active area is dependant on the vapor density and weir loading. Note that the weir loading need not be known at this point. Assume a weir loading value of 5 gal/min per in. intially. Typical tray spacings are 24 in.

## Tower area and diameter

Based on the above areas, the overall tower area and diameter can be determined by the following:

$$A_T = A_{Dtop} + A_{Dbottom} + A_A$$
$$D = 2(A_T / \pi)^{0.5}$$

Where,
$A_T$ = Tower area, $ft^2$
$A_{Dtop}$ = Downcomer area at top, $ft^2$
$A_{Dbottom}$ = Downcomer area at bottom, $ft^2$
$A_A$ = Active Area, $ft^2$
$D$ = Tower inner dia., ft

## Number of downcomers

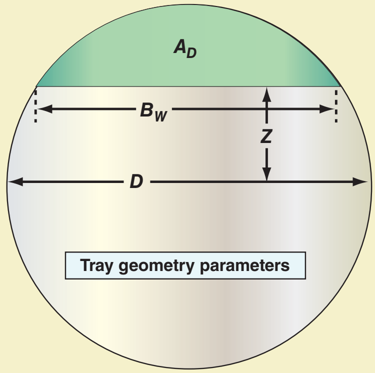
Once the tower diameter is determined, then the number of downcomers can be chosen. As a starting point, an initial design should use a single downcomer. The resulting weir length is calculated from a standard chord-length calculation, which is iterative for a given downcomer area.

$$B_W = \{[(\pi D^2/360)\cos^{-1}(2Z/D)] - 2A_D\}/Z$$

Where,
$Z = [(D^2/4) - B_W^2]^{0.5}$
$B_W$ = Weir length of one downcomer, ft

A good place to start the iterative process is with a weir length 0.8 times the tower diameter. If the resulting weir loading is greater than 12 gal/min per in., then increase the number of tray passes to two. Recalculate the outlet weir length for each of the side downcomers of the column by using half the downcomer area. Check the weir loading again (for the tray with side downcomers). If the weir loading continues to exceed 12 gal/min per in., increase the number of tray passes to four. It is assumed that the two-pass tray with side downcomers has the shortest weir length.

The simplest approach to designing 4-pass trays is to assume equal bubbling area and make the side downcomers one-quarter of the total downcomer area, and make the center (and off-center) downcomers one-half of the total downcomer area.




**Tray geometry parameters**

Maintaining the resulting downcomer widths at 6 in. or more will allow a person to reach into the downcomer for installation. In addition, make sure the resulting tray-flow path-length is 16 in. or greater to enable a person to physically pass through the trays. These minimum size criteria may increase the column diameter to above the previously calculated value.

## Other considerations

Other criteria that need to be considered are; downcomer backup, spray fluidization, and entrainment. In addition, minimum load conditions need to be determined. The criteria for determining the low-end vapor and liquid range are weeping, tray stability and dry-tray pressure drop.

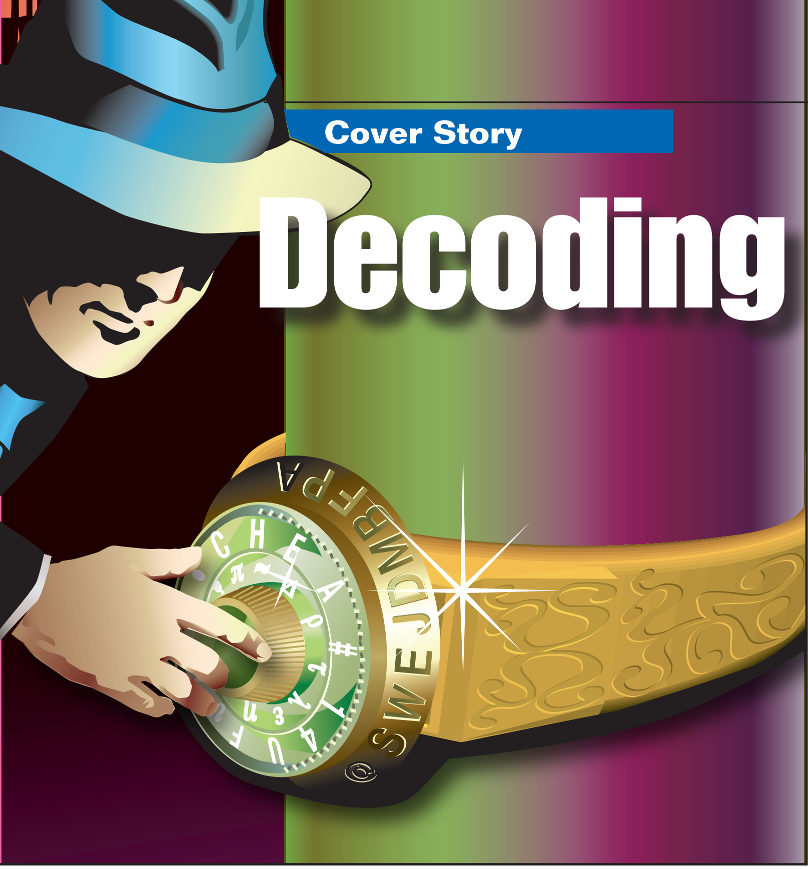
## Reference

1. Glitsch Inc. "Ballast Tray Design Manual; Bulletin No. 4900." 3rd Ed. Glitsch Inc., Dallas, Tex.,1974.

*Note*: Material for the June "Facts at Your Fingertips" was supplied by Dan Summers, tray technology manager, Sulzer Chemtech USA Inc.

Cover Story

# Decoding Pressure Vessel Design



## Bridging the gap between users' and manufacturers' responsibilities for the ASME pressure vessel code

**Keith Kachelhofer**,
Jedson Engineering Inc.

Tracing its origins to 1915, the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (the code) [*1*] has become the established safety standard governing the design, fabrication and inspection of boilers and pressure vessels, as well as nuclear power plant components during construction. Section VIII, Division I of the code addresses pressure vessels operating at either internal or external pressures exceeding 15 psig.

Despite the prevalence of pressure vessels in the chemical process industries (CPI), a clear understanding of the basis-of-design responsibilities involved in designing, fabricating and repairing such a device remains elusive. Vessel users are responsible for providing all necessary data to ensure the manufacturer can design and fabricate a pressure vessel in full compliance with the code.

The lack of clear understanding can result in a disconnect between users and manufacturers during pressure vessel specification. The disconnect is often magnified because, although Section U-2(a) of the ASME Code clearly defines the responsibilities for establishing the basis of design, users often lack access to the code language and its associated interpretations. Basis of design refers to well-defined information that could form the foundation for inspection and test acceptance criteria.

While engineering specifications often provide sufficient data for a manufacturer in certain basic areas — such as internal and external pressure, temperature, vessel orientation, material of construction, corrosion allowance and vessel contents — pressure vessel fabricators usually receive insufficient information from users in areas such as wind, seismic and external loadings. The incomplete specification information makes a proper and complete vessel design difficult and can lead to inaccurate price quotes. Providing complete information will help avoid cost overruns and change-orders.

The intent of this article is to clarify those areas of pressure vessel specification where information is commonly omitted and areas where further clarification is required. Further, this article is intended to improve understanding of which responsibilities are shouldered by vessel users and which by manufacturers. By providing a more comprehensive basis of design for a vessel, users and manufacturers can save money and formulate specifications with public safety in mind.

All 50 U.S. states, all Canadian provinces and many local jurisdictions and territories have formally adopted the ASME Code as a safety standard for boilers and pressure vessels. Each jurisdiction employs a chief inspector who is a member of the National Board of Boiler and Pressure Vessel Inspectors. Meanwhile, the code is frequently a prevailing basis in other countries throughout the world.

## VESSEL DESIGN

### Design versus operating *T* and *P*

In engineering specifications, often no distinction is made between the design pressure and operating pressure. Section UG-21 of the code recommends a suitable design pressure above the operating pressure of the vessel at which the vessel will normally operate. The operating pressure should represent the most severe exposure of pressure and temperature the vessel is expected to experience under normal operating conditions, whereas the design pressure should allow for potential pres-

**TABLE 1. SURFACE FINISH COMPARISON**

| Grit finish | Ra (microinch) | RMS (µm) |
|---|---|---|
| 36 | 142 | 4.06 |
| 60 | 87 | 2.49 |
| 80 | 71 | 2.03 |
| 120 | 52 | 1.47 |
| 150 | 42 | 1.20 |
| 180 | 30 | 0.86 |
| 220 | 19 | 0.53 |
| 240 | 15 | 0.43 |
| 320 | 12 | 0.36 |
| 400 | 9 | 0.25 |
| Mirror | +/- 4 | 0.13 |

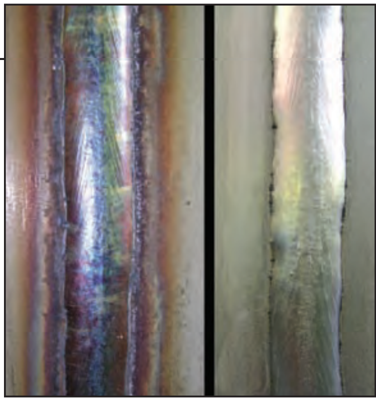


**FIGURE 1.** The pickling process removes the heat tint produced during welding (left = before; right = after)

sure surges up to the setting of the pressure-relief device. The design temperature should account for the lowest and highest operating temperature, in addition to operational upsets, atmospheric temperature and other sources of cooling. The design and operating conditions should be established in a process safety review meeting within the user's organization.

Based upon the material of construction, the nominal plate thickness and the minimum design temperature, the manufacturer will have to determine the requirements for welding. For carbon steel and low-alloy vessels, the requirement for Charpy impact testing can be determined in Section UCS-66 of the code. For high-alloy vessels, such as those fabricated of austenitic stainless steel, the manufacturer will refer to Section UHA-51 of the code. The manufacturer will determine if impact testing is required and if the shop has a qualified weld procedure to meet the requirements of the Code.

## Vessel contents

With regard to vessel contents, the key phrase for the fabricator is "lethal service." Vessels are considered lethal service if the contents, whether mixed with air or alone, are dangerous to life when inhaled. Lethal service imposes mandatory Code-compliance requirements on the manufacturer, such as 100% radiography of all welds. These requirements can substantially increase the vessel's fabrication cost.

If the process involves hydrogen sulfide, where there is a risk of sulfide stress cracking, then the manufacturer needs to be advised of the requirements of the National Association of Corrosion Engineers (NACE) standard RP0472 and NACE publication 8X194. Hydrogen sulfide service will have restrictions for material-grade, post-weld heat treatment, and allowable hardness of the weld and heat-affected zone; all of which will impact the manufacturer's cost for fabrication. The user should identify dangerous compounds in its process and address the dangers in a process safety review meeting.

The user should provide the specific gravity of the process fluid, since the manufacturer must account for the additional static pressure due to the static head of the liquid, per section UG-22(b).

## Materials of construction

While the material of construction is commonly included in equipment specifications, clarification is often required as to the impact the material specification has on the fabrication and the quote. Information in the specification should allow the manufacturer to determine whether or not its qualified weld procedures and qualified welders are sufficient for the alloy specified. In cases where the manufacturer has to qualify a procedure for an alloy not commonly welded in the shop, the cost impact should be evaluated.

The material specification and the grade designation should also be provided to the manufacturer. For example, if the vessel is fabricated from austenitic stainless plate, then indicate the ASTM International (ASTM) specification and grade, such as: A240-316L. For the nozzles the specification and grade will be A312-316L. If the process safety review determines that seamless pipe is required for the nozzles, then this should be clarified, since it will impact the vessel's cost. For flanges, the specification and grade will be A182F-316L. Depending on the process, some users may prefer using a carbon-steel backing flange in conjunction with a stainless-steel stub-end. If that is the case, clearly indicate it in the specification.

A material specification for appurtenances is commonly not given. Items such as lifting lugs, support lugs, skirts and support legs can often be specified with a different grade material than that of pressure retaining items. The user may have a vessel where all of the pressure-retaining items and wetted surfaces are 316L stainless steel, but the lifting lugs and support ring may be fabricated from 304 stainless steel. Depending on the user and the service, a stainless-steel vessel with carbon-steel legs might be acceptable, provided there is a "poison pad" between the two materials such that the pressure-retaining items are not at risk of carbon contamination. Often manufacturers will specify an alternate material grade for appurtenances in order to minimize fabrication cost. If alternate material grades are unacceptable for appurtenances, that should be stated in the specification, particularly when manufacturers are competitively bidding for the contract.

## Stainless-steel surface finish

For users in the food-and-beverage and pharmaceutical industries, there are often requirements for special internal- and external-surface finishes. Ambiguity and different interpretations about user expectations and manufacturer capabilities can arise when the mechanical finish is specified as one of the following: satin, polished, bright, dull or mirror. Parameters such as contact time, material feedrate, abrasive pressure and application of lubrication will have an impact on the finished product. Special finishes supplied by the manufacturer are not published by ASTM International.

Polishing and grinding involve the removal of metal from a surface with an abrasive, resulting in surface directional marks. There is no definition of an abrasive grit size that differentiates grinding from polishing. As a guide, however, grit sizes of 80 and coarser can be associated with grinding, whereas grit sizes of 120 and finer can be associated with polishing. Nevertheless, simply specifying the grit size cannot

| TABLE 2. GUIDELINE FOR HEAD THINNING DURING FORMING | |
|---|---|
| Head thickness range | Allowable thinning during forming |
| 12-gauge, up to and including 0.25-in. plate | 0.032 in. |
| 5/16-in. nominal thicknesses up to and including 0.5-in. plate | 0.062 in. |
| 9/16-in nominal thickness up to and including 1.0-in. plate | 15% |

be equated to a specific surface finish.

Buffing is not intended to remove metal from the surface. It is intended to brighten and smooth the existing surface with cotton- or felt-based media and with the application of lubricants to the buffing wheel.

For precise and consistent results, it is recommended that the surface finish be specified in a range of minimum and maximum level of roughness average (Ra). This can be expressed in microinches or micrometers (Table 1).

The Specialty Steel Industry of North America (SSINA) publishes a designer handbook of specialty finishes for stainless steel, which provides detailed descriptions and sample photographs. The handbook can be downloaded free of charge at www.ssina.com. Photographs for comparison of certain standard finishes (Nos. 1, 2B, 2D, 2BA, 3, 4, 6, 7 and 8) for sheets or various nominal thicknesses can also be found at the website.

## Vessel heads

Some of the most common heads in service are as follows: ASME flanged and dished (torispherical), 2:1 elliptical flanged and dished (ellipsoidal), conical, toriconical, hemispherical and flat.

Heads are formed based upon outside vessel diameter, with the exception of elliptical and hemispherical heads, which are formed to the inside diameter. When ordering the head, the vessel manufacturer will provide the head manufacturer with the minimum permitted thickness that is required based upon the calculations. Thinning of the vessel head takes place primarily at the knuckle regions and the center of the dish (Table 2).

***Torispherical heads.*** Torispherical heads have dish radii equal to the diameter of the head or vessel shell, and the knuckle is 6% of the head inside-crown radius as required by Section UG-32(e) of the ASME Code (Figure 2). The straight flange (skirt) is a standard 1.5 in. for heads formed from 3/16-in. plate and heavier. Straight flanges up to 2 in. can be provided upon request. For some head manufacturers, a 3-in. straight flange can be provided for head diameters ranging from 36 to 54 in. as long as there is a minimum plate thickness of 3/16 in. For heads 54 in. and larger, a 3-in. straight flange can be provided with a minimum plate thickness of 0.25 in.

When specifying a torispherical head for a pressure vessel, it is important for the user to clearly define an ASME flanged and dished (torispherical) head. Standard flanged and dished heads are manufactured, but do not meet the code requirement of a minimum 6% inside-crown radius for the knuckle region. As a result, the standard flanged and dished heads provide a higher stress concentration factor and discontinuity in the knuckle region. Some manufacturers offer an ASME 80–10 head where the dish radius is 80% of the head diameter and the knuckle radius is 10% of the head diameter. The advantage of an ASME 80–10 head is that it is thinner (~66% of the thickness of an ASME torispherical head), which results in a smaller blank size and reduced labor cost.

A third option for a torispherical head is an ASME high-crown head, where the dish radius is 80% of the head diameter and the knuckle radius is a minimum of 6% of the head diameter.

***Ellipsoidal (2:1) head.*** A 2:1 elliptical flanged and dished head provides a dish radius that is approximately 90% of the inside head diameter and a knuckle that is approximately 17.3% of the inside head diameter. The geometry of the ellipsoidal head is provided in Section UG-32(d) of the ASME Code.

The decision of whether to specify and use a torispherical head versus an ellipsoidal head is mainly an issue of head clearance. Users should decide which head better suits their needs.

If a dished head requires a bolting flange, then the manufacturer must design the head and flange in accordance with the code's Appendix 1 (1–6). The cost of adding a bolting flange is significant.

***Toriconical heads.*** The transition geometry of a toriconical head is typically limited to a maximum half-apex angle of 30 deg (Figure 3). The knuckle cannot be less than 6% of the outside diameter of the head skirt or less than three times the calculated knuckle thickness as outlined in UG-32(h).

Toriconical heads or transitions may be used when the half-apex angle is greater than 30 deg and further requires the design to be in compliance with the mandatory Appendix 1 of the code. A conical head or transition does not have a knuckle. Therefore a reinforcing ring is required by Appendix 1–5(d) and (e). Half-apex angles greater than 30 deg for conical heads and transitions shall be in accordance with Appendix 1–5(g) of the code.

***Un-stayed flat heads.*** These can be incorporated into the design, but have limitations in pressure and temperature due to their geometry (Figure 4). Section UG-34 of the code provides the design requirements for un-stayed flat heads and covers. This includes bolted blind flanges, flat plates with retaining rings, and threaded covers. The section provides nineteen examples of un-stayed flat heads that can be used, but clarifies that other designs, which meet the requirements of UG-34, are acceptable.

The user may have an un-stayed flat head design that is to be incorporated. If so, users should provide a sketch of what is desired and allow the manufacturer to bring the proposed design into compliance with the code.

Details are needed when specifying closure heads on a pressure vessel. When specifying the vessel shell length, reference it from the tangent line of one head to the tangent line of the opposite head. The tangent line is an accepted datum for most shops.

## Nozzle schedule

Most users generally provide a nozzle schedule, but significant information is inherently omitted. When providing a nozzle schedule, the manufacturer is focused on size, type and quantity. The physical placement of the nozzles, and their projections can be addressed during the drawing review process (Figures 5 and 6). The user needs to be clear on the types of flanges required — raised-face slip-on flanges, raised-face weld-neck flanges or lap-joint flanges with stub-ends. When stub-ends are considered, be sure to clarify

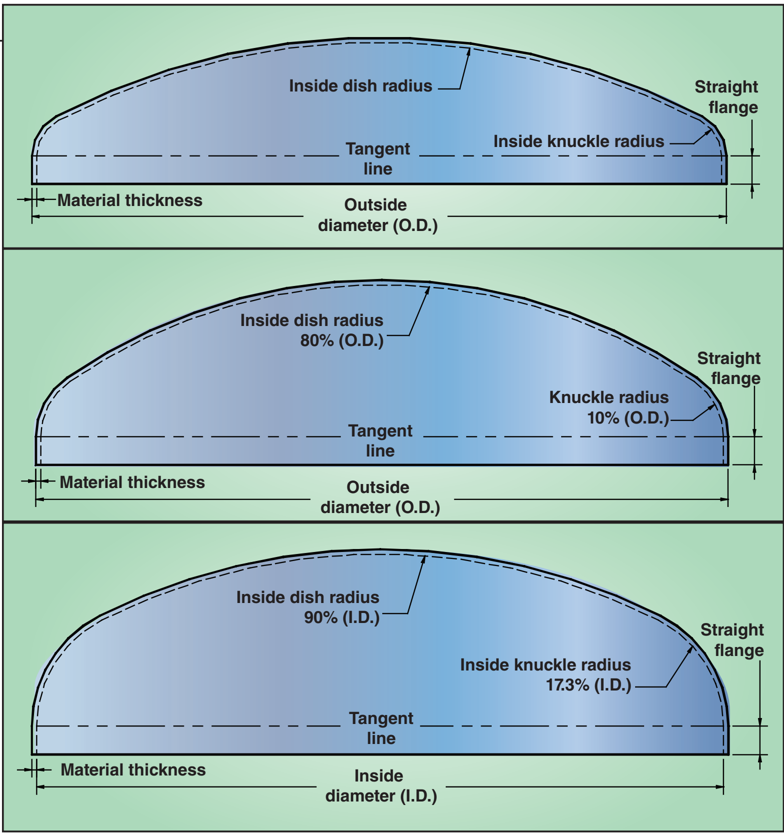



**FIGURE 2.** The geometry of an ASME 80-10 torispherical head is such that the dish radius is 80% of the head diameter and the knuckle radius is 10% of the head diameter, while an ellipsoidal head has a dish radius that is 90% of the inside head diameter and a knuckle 17.3% of the inside head diameter

Type A or B stubs ends. For the nozzle necks and any internal piping, specify electric-resistance-welded (ERW) pipe or seamless pipe (SMLS). Seamless pipe cost is considerably higher and will increase the vessel's cost. The manufacturer is responsible for determining if the nozzle requires a reinforcement pad.

Users should also define the nozzles used for inspection and overpressure protection. If there is not a safety relief device attached directly to the vessel, most users will not identify an overpressure protection nozzle. If the safety relief device is not directly attached to the vessel, identify the nozzle connected to the piping system containing the safety relief device. If the vessel has a manway opening then clarify whether or not a hinge or davit arm is required. If the vessel requires a stud pad or sight glass, then specify it.

A manufacturer and model number for the sight glass should be provided with the vessel specification so the manufacturer can obtain a quote. For stud pads, be sure to specify the size and flange rating for the pad.

## SAFETY AND TESTING

### Corrosion allowance

The user should also specify a corrosion allowance for the vessel according to Section UG-25 of the pressure vessel code. The only situation for which a corrosion allowance is not required in the specification is when experience in "like service" has proven corrosion did not occur or the corrosion is superficial. Both the internal and external surfaces of the vessel should be considered.

If the vessel is subject to internal corrosion, then the design should incorporate a drain nozzle at the lowest point or a pipe extending into the vessel from any other location to within 0.25 in. of the lowest point.

Depending on the service, the user may elect to have telltale holes drilled part of the way into the pressure retaining items. The code requires the holes to be 1/16-in. to 3/16-in. dia. The holes' depth must be greater than 80% of the thickness required for a seamless shell of like dimensions. The holes should be on the surface opposite where the deterioration is expected. Telltale holes are not permitted in vessels intended for lethal service.

### Non-destructive examination

A common oversight is the specification of the degree of non-destructive examination (NDE) testing that is required. Radiographic examination is the most common method of NDE and is incorporated into the code to establish joint efficiencies for the weld seams.

All radiographic examination should be in accordance with Section VIII, Division I, UW-51 and with Article 2, Section V of the code. Section UW-52 provides the minimum extent of spot radiography, as well as procedural standards, evaluation and retesting. When specifying NDE, be sure to clarify what level is required. Radiography will increase the cost of the vessel.

### Inspection openings

Inspection openings are important for routine inspections of the vessel for safety and life expectancy. Elliptical manhole openings are permitted by the code provided the opening is not less than 11 in. by 15 in. or 10 in. by 16 in. and a circular manhole is not less than 15-in. inside diameter (ID).

For hand-holes, the minimum size restriction is 2 in. by 3 in., except for vessels over 36 in. dia. where the minimum size handhole is 4 in. by 6 in. and is used in place of a manhole. If the vessel is less than 18 in. ID but over 12 in. ID, the code requires the vessel to have at least two handholes, or two plugged and threaded inspection openings, no smaller than 1.5 in. nominal pipe size (NPS).

For vessels with ID between 18 and 36 in., the code requires either a manway, two handholes or two plugged, threaded inspection openings not less than 2 in. NPS. For vessels with IDs in excess of 36 in., the code requires one manway opening, with the exception that two 4- by 6-in. handholes can be used if the vessel geometry does not permit a manway.

Nozzles attached to piping or instrumentation can be used for inspection openings, provided the openings meet the required size and are located to afford an equal view of the interior of the vessel. It is the user's responsibility to identify the

| TABLE 3. EXAMPLES OF COMBINED LOADINGS | | | |
|---|---|---|---|
| Design Pressure in Inner Vessel, psig | Design Pressure in Annulus, psig | Pressure Used for Design of Inner Vessel, psig | Pressure Used for Design of Jacket, psig |
| +250 | +50 | +250 and –50 | +50 |
| -15 | +200 | –215 | +200 |
| +100 and -15 | +150 | +100 and–165 | +150 |

inspection openings on the vessel prior to design and fabrication.

### Overpressure protection

All vessels are required to have overpressure protection in accordance with Section UG-125 of the code. The relief device can be located directly on the vessel or installed within a process or utility pipeline connected to the vessel. In either case, authorized inspectors may require identification of the nozzle that will be connected to the safety relief device. The identification of the nozzle for safety relief is the responsibility of the user and should be discussed internally during the user's process safety review.

### Stainless-steel surface treatment

Users requiring a stainless-steel vessel often do not provide specifications for cleaning the vessel prior to shipment. Stainless-steel surfaces and welds require special surface treatments in order to remove light surface contamination. During fabrication, a vessel may be exposed to shop dirt, carbon-steel particles, permanent marker, crayon marker, oil and grease — all contaminants that can accelerate corrosion. Carbon steel particles and iron can become embedded in the plate and heads due to routine shop handling, forming rolls, layout tables, cutting tables and carbon-steel grinding operations.

The most complete resource for cleaning stainless steel is ASTM International A380-06 (Standard Practice for Cleaning, Descaling and Passivation of Stainless Steel Parts, Equipment and Systems) [*2*]. The standard recommends the user precisely define the intended meaning of passivation since there are several distinct operations.

The first of these operations is defined in Paragraph 1.1.1 of ASTM Standard 380, where passivation is a process by which a stainless-steel surface, when exposed to air or other oxygen-containing environments, will spontaneously produce a chemically inactive surface. It is now accepted that this film will develop in an oxygen-containing environment provided the surface has been thoroughly cleaned and descaled.

For most users, passivation is the removal of iron compounds from the surface of stainless steel by means of a chemical dissolution. This is accomplished with an acid solution that will not etch the surface or have significant effects on the material. Some methods involve cleaning the vessel with a 20–25 vol.% nitric acid solution at 120°F for 30 min. The nitric acid solution removes contaminants and oxidizes nickel on the surface to form a chromium-oxide film on the surface and thus prevent further corrosion and oxidation.

Citric-acid treatment is the least hazardous and most environmentally safe method for removal of free iron and other metal and light surface contamination. Citric acid is preferred with most manufacturers, since no special handling equipment or safety devices are required; no NOx fumes are released and no corrosion occurs in nearby equipment that might come in contact with the solution. Typical citric acid solutions are 4–10 wt.%. Spraying the solution and lightly scrubbing the surface with a soft brush is the preferred method for cleaning large vessels.

The user must be aware that a passivation treatment includes degreasing, immersion and rinsing. The degreasing process is crucial since air cannot form a protective film when grease or oil is present on the surface. Therefore, it is important that the manufacturer clean the vessel with a commercial-grade degreaser prior to passivation. After treating the vessel with nitric or citric acid, a thorough rinse with clean water should follow without allowing the surface to dry between steps.

The pickling process removes the heat tint produced during welding operations (Figure 1). Since nitric and citric acids do not remove surface layers, pickling removes the protective oxide layer between 0.001 and 0.0015 in. of the substrate layer. Pickling paste, nitric-hydroflouric acid ($HNO_3$–HF), is typically applied with a nylon brush and can only be left in contact for 15–30 min before excessive corrosion is initiated. Similar to the passivation treatments with nitric acid, shop personnel will need to wear the proper protective clothing and receive proper training for handling the product.

ASTM standard A380 also addresses mechanical cleaning, including such processes as power brushing, sanding, chipping, grinding and abrasive blasting. For removal of localized areas of scale, grinding is typically the most effective. To avoid the risk of contaminating the stainless steel, grinding operations have to be carefully monitored to ensure the grinding wheels being used have not been previously used on carbon steel plate. However, the standard does not recommend abrasive blasting with silica, since it is nearly impossible to remove the embedded silica from the surface of the material. Walnut shells or glass beads are the preferred media for abrasive blasting.

## EXTERNAL LOADINGS

Section UG-22 of the code provides a short list of various external loading conditions that need consideration, including the following: wind, snow, seismic loadings, as well as superimposed static and dynamic reactions from attached equipment, such as machinery, piping and insulation. While most specifications issued to fabricators cover the bare necessities for sizing a new vessel, many exclude external loadings. Some specification sheets are incomplete, such as those requesting consideration for wind and seismic loadings.

Specifications typically will reference the required code for wind and seismic loadings, such as American Society of Civil Engineers (ASCE) Standard 7-05 Minimum Design Loads for Buildings and Other Structures [*3*]. However, they often do not provide specific information on the vessel's geographical location, the wind exposure category, the elevation of the vessel from grade or the importance factor. Without these details, the wind and seismic loadings provide an inaccurate picture as to what the vessel might see in an upset condition. The ASME

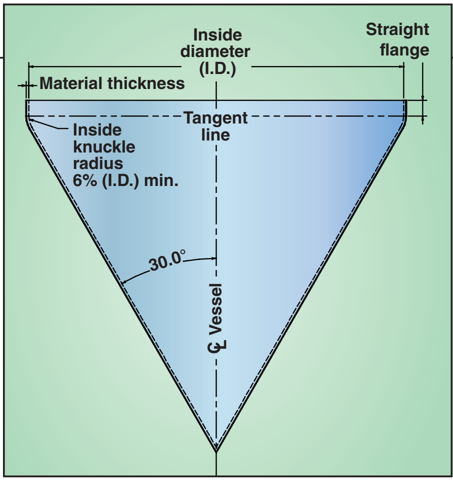



**FIGURE 3. Toriconical heads and transition geometries are limited to a maximum half-apex angle of 30 deg**

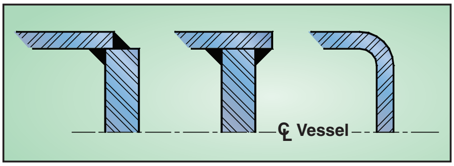



**FIGURE 4. Requirements of un-stayed flat heads and covers include bolted blind flanges, flat plates with retaining rings and threaded covers. Here are a few examples**

Boiler and Pressure Code, Section VIII is referenced in ASCE 7-05.

***Seismic loadings.*** Section 15.7.2 (c) of ASCE 7-05 requires hydrodynamic vertical, lateral and hoop forces to be considered in cylindrical tank and vessel walls. These forces shall be evaluated to determine the increase in hydrostatic pressure and hoop stress.

In addition, Section 15.7.3 requires the evaluation of all structural components that are an integral part of the lateral support system. The evaluation should ensure that connections and attachments for anchorage and other lateral-force-resisting components, as well as nozzle penetrations and openings are designed to maintain structural stability and integrity of the shell. Vessel stiffness in relation to the support system should be used to determine the forces on the vessel. If the vessel is oriented horizontally, then analysis is required at the saddle supports per Section 15.7.14.3. The combination of these loads should be used to establish the maximum allowable working pressure of the vessel as outlined in Code Interpretation VIII-1-01-03.

***Wind loadings.*** Wind loadings are covered in Section 6.5 of ASCE 7-05. The design procedure for wind loadings on pressure vessels requires determining wind speed, importance factor, exposure category, topographical factor and gust factor. The wind speed is obtained from ASCE 7-05., which provides a map of the U.S. with basic wind speeds for various locations, including special wind areas at the hurricane coastlines of the following regions: the west coast of Mexico, the eastern part of the Gulf of Mexico and the Southeast U.S. and the Mid- and North Atlantic. It is important to understand that it is assumed that the wind could come from any horizontal direction. Where there is mountainous terrain, gorges or other special wind regions, there can be an adjustment made to the values in Figure 6-1 of the code to account for higher local wind speeds. This adjustment shall be based on local meteorological information.

The occupancy category is provided in Table 1-1 of ASCE 7-05. The occupancy category is based upon the nature of occupancy during upset conditions involving excessively high winds or earthquakes. The categories for occupancy range from Occupancy Category I (buildings with low hazard to human life in the event of catastrophic failure) to Occupancy Category IV (essential facilities, such as hospitals). Facilities that manufacture or process hazardous fuels, hazardous chemicals, hazardous waste or explosives are considered to be an Occupancy Category III. If the hazardous material exceeds a threshold quantity established by a local jurisdiction, then the vessel is classified as Occupancy Category IV. The importance factor for wind loadings is provided in Table 6-1 of ASCE 7-05 and is based upon the occupancy category.

Pressure vessels are placed into one of three exposure categories (B, C or D), which depend on ground surface roughness. To derive the exposure category, surface roughness must first be defined. Surface roughness is determined by natural topography, vegetation and nearby buildings and structures. Surface roughness category B is defined as suburban areas and wooded areas with numerous, closely spaced obstructions the size of a single-family house or larger. Surface roughness C is defined as open terrain with scattered obstructions of heights less than 30 ft. This category encompasses flat open country, grasslands and water surface areas in hurricane-prone regions. Surface roughness D is characterized by flat, unobstructed areas outside of the hurricane-prone regions. This includes salt flats, mud flats and unbroken ice.

A vessel's surface-roughness category is then used to determine its exposure category. Exposure category B is defined by surface roughness B with the wind prevailing in the upwind direction for a distance of at least 2,600 ft, or 20 times the height of the building, whichever is greater.

Exposure category C is used for cases where Exposures B or D are not applicable. Exposure D applies when the surface roughness is defined as surface roughness D, where the prevailing wind direction is upwind for a distance of 5,000 ft or greater. Exposure D can also apply to surface roughness B or C for a distance of 600 ft, or 20 times the height of the structure, whichever is greater. If the site under consideration is located in a transition zone between exposure categories, then the largest wind forces apply.

Topographical effects only need to be considered for increased wind speed over hills and ridges. Section 6.5.7 of ASCE 7-02 provides detailed procedures for calculating topographical effects. The gust effect factor for rigid structures should be 0.85, per Section 6.5.8.1, or should be calculated. If the vessel is dynamically sensitive, then Section 6.5.8.2 of ASCE 7-05 provides the necessary steps to calculate the gust effect factor.

These five constants and categories provide sufficient data for the fabricator to properly design the vessel for wind loadings. The ASME Code requires manufacturers to consider the combination of the vessel design pressure along with the secondary stresses from wind or seismic loads.

***External piping loads.*** External nozzle loadings are typically overlooked, especially those loadings imposed by high-temperature piping. It is the user's responsibility to notify the

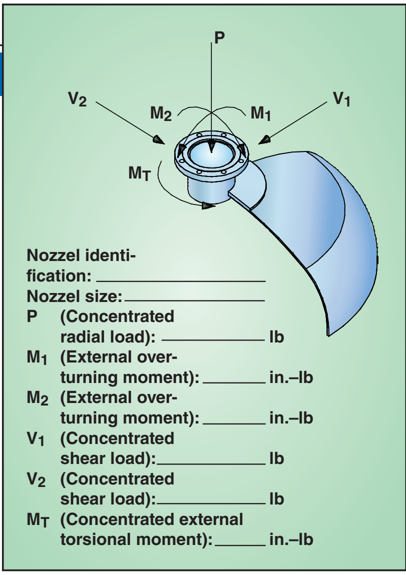



**FIGURE 5. It is the vessel user's responsibility to notify the fabricator as to whether the piping imposes excessive loadings on the nozzles**

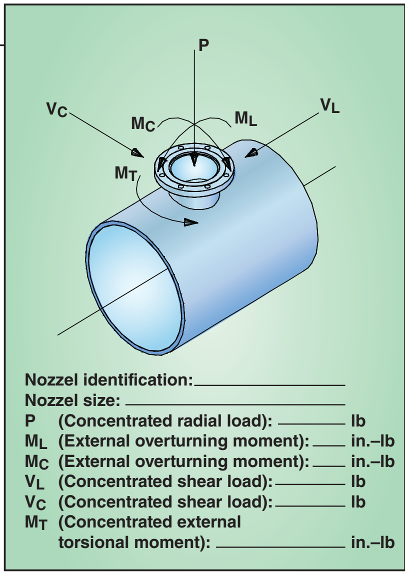



**FIGURE 6. Agitators and mixers are sources of external nozzle loading. Users should obtain the mixer reaction loads from their maker, and relate that to the vessel manufacturer**

fabricator if the piping may impose excessive loadings on the nozzles. This includes excessive loadings during normal operating conditions and during upset conditions. Section 15.7.4 of ASCE 7-05 requires the analysis of the piping system connected to the vessel during earthquake conditions.

The piping system and supports shall be designed such that there is no excessive loading on the vessel wall. The assumption that a nozzle is an anchor point for piping is poor practice. Stresses need to be considered in the shell/head at the nozzle-to-shell juncture. Therefore all external loads are considered to be acting simultaneously. All external loads, such as the longitudinal and circumferential shear loads and moment loads, have to be considered with the radial and torsional loads in conjunction with the design pressure of the vessel.

These loads can be analyzed per the Welding Research Council (WRC) Bulletin 107 and its supplement (Bulletin 297 — for cases where the stress is evaluated in the shell only) [*4,5*]. Calculating loads with WRC 107 and 297 is time-consuming if performed manually, because numerous non-dimensional geometric parameters have to be interpolated from multiple charts. Computer software programs are available to aid calculations.

## External equipment loads

Agitators and mixers are another source of external nozzle loadings. Obtain the mixer reaction loads from the equipment manufacturer and relate these loads to the vessel manufacturer. The mixer reaction loads have an impact on the cost of the vessel if a reinforcement pad, or gussets are required, or if the plate thickness on the vessel head needs to be increased. Some users have invested significant expense to replace wrecked agitators due to flexing nozzles. Calculating the stress on the vessel shell and nozzle is the same as those calculations for piping nozzles using the WRC 107 / WRC 297 procedures.

## JACKETED VESSELS

Jacketed vessels are addressed in Appendix 9 of the ASME Code. Appendix 9 applies to the jacketed portion of the vessel, which includes the wall of the inner vessel, the wall of the jacket, and the closure between the inner vessel and the jacket. The manufacturer shall consider the combined loading of the vacuum/pressure on the jacket wall along with the pressure/vacuum within the inner vessel wall and determine which of these is greater than the individual loading (Table 3).

The code categorizes jacketed vessels, which provides a convenient method to assign closures.

- Type 1 – Jacket (any length) confined entirely to cylindrical shell
- Type 2 – Jacket covering part of the cylindrical shell and one head
- Type 3 – Jacket covering any portion of the head
- Type 4 – Jacketed with an added stay or equalizer rings to the cylindrical shell portion to reduce the effective length
- Type 5 – Jacket covering the cylindrical shell and any portion of either head

Half-pipe jackets are covered in a non-mandatory appendix of the code, Appendix EE. The calculation procedure in the code is for the conditions where there is positive pressure in the vessel shell or head and positive pressure in the half pipe jacket. The code further provides restrictions to half pipe jacket sizes of NPS 2, 3 and 4 with vessel diameters ranging from 30 to 170 in. The code does permit jackets of other geometries, such as circular segments, channels or angles.

The vessel manufacturer should consider other combinations of pres-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sure loadings outside of what is provided in the rules of Appendix EE. These include the following:

- Negative pressure inside the vessel and inside the jacket
- Negative pressure inside the shell and positive pressure inside the jacket
- Positive pressure inside the vessel and negative pressure inside the jacket
- External nozzle loadings from piping connections
- Cyclic loadings to any of the above combinations

When specifying the half pipe jacket be sure to provide the manufacturer with the pipe size required, the pitch of the coils, the design temperature and the design pressure. An approximate location of the half-pipe inlet and outlet nozzles is beneficial for the manufacturer to determine potential interferences with other nozzles on the vessel.

Dimpled and embossed jackets are another form of jacket assemblies and are addressed by Appendix 17, a mandatory appendix of the Code. If the manufacturer is using a plate that has been dimpled or embossed prior to welding, then a proof test shall be performed in accordance with Section UG-101 of the code. The proof test requires the use of a representative panel, which is rectangular with at least five pitches in each direction and not less than 24 in. in either direction. A proof test can add additional cost to the fabrication of a vessel.

It is strongly recommended that if a vessel requires any type of jacket, the user should provide a supplemental specification sheet with a drawing of the vessel and the required location of the jacket(s). The required surface area and heat transfer calculations are the responsibility of the user. ■

*Edited by Scott Jenkins*

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# Piping Design for Hazardous Fluid Service

**William M. Huitt**
W.M. Huitt Co.

## Extra considerations and precautions are needed beyond the requirements of codes and standards

Incorporating fire safety into plant design takes on two fundamental goals: to prevent the occurrence of fire and to protect the initially uninvolved piping and equipment long enough for operations personnel to perform their duties and for emergency responders to get the fire under control. While it is impractical to completely eliminate the potential risk of an accidental fire in a complex process-plant facility that is expected to handle and process hazardous chemicals, it is reasonable to assume that certain aspects of design can be incorporated to reduce that risk.

Designing facilities that use and store hazardous chemicals requires a demanding set of requirements, at times beyond what can practically be written into industry codes and standards. It is ultimately the responsibility of the engineer of record (EOR) and the owner to fill in those blanks and to read between the lines of the adopted codes and standards to create a safe operating environment, one that minimizes the opportunity for fire and its uncontrolled spread and damage.

This article will not delve into the various trigger mechanisms of how a fire might get started in a process facility, but will instead discuss containment and control of the fuel component of a fire that resides in piping systems that contain combustible, explosive or flammable fluids.

In the design of piping systems containing such fluids, there are critical aspects that need additional considerations beyond those involved in the design of piping systems containing non-hazardous fluids. There are two key safety aspects that need to be incorporated into the design, namely system integrity and fire safety.

### System integrity

System integrity describes an expectation of engineering that is integrated into the design of a piping system in which the selected material of construction (MOC), system joint design, valve selection, examination requirements, design, and installation have all been engineered and performed in a manner that instills the proper degree of integrity into a piping system. While this approach is certainly needed for the piping design of so-called normal fluid service it is absolutely critical for hazardous fluid systems.

The design of any piping system, hazardous or non-hazardous, is based, in large part, on regulations and industry accepted standards published by such organizations as the American Society of Mechanical Engineers (ASME) and the American Petroleum Institute (API). The standards published by these organizations include tables that establish joint-pressure ratings based on MOC and temperature. Where the joint-design consideration for hazardous fluid services departs from that of non-hazardous fluid services is in gasket and seal material specifications.

This is due to the need for sealing material to contain hazardous chemicals for as long as possible while surrounded by a fire or in close proximity to a fire. The effect of heat from a fire on an otherwise uninvolved piping system can only be delayed for a relatively short period of time. And the first thing to fail will be the mechanical type joints.

Depending on the type of fire and whether the piping is directly in the fire or in close proximity, the window of opportunity, prior to joint seal failure, for an emergency response team to get the fire under control is anywhere from a few hours to less than 30 minutes. As you will see, a number of factors dictate the extent of that duration in time.

A system in which the gasket material is selected on the basis of material compatibility, design pressure, and design temperature may only require a solid fluoropolymer. In a fire, this non-metallic material would readily melt, allowing the contents of the pipe to discharge from the joint once sealed by the gasket. Specifying a gasket that is better suited to hold up in a fire for a longer period of time gives the emergency responders time to bring the initial fire under control, making it quite possible to avoid a major catastrophe.

### Fire-safe system

Preventing the potential for a fire requires operational due diligence as well as a proper piping-material specification. However, controlling and restricting the spread of fire goes beyond that. Results of the assessment reports of catastrophic events coming from the U. S. Chemical Safety and Hazard Investigation Board (CSB; Washington, D.C.) have shown that many of the occurrences of catastrophic incidents have actually played out through a complex set of circumstances resulting from design flaws, instrumentation problems, pipe modifications, inadequate fire-proofing and human error.

Events, such as a fire, are not necessarily then the result of a hazardous fluid simply escaping through a leaky joint and then coming into contact with an ignition source. There are usually a complex set of events leading up to a fire incident. Its subsequent spread,

## INCIDENT NO. 1 VALERO-MCKEE REFINERY, SUNRAY, TEX., FEB. 16, 2007

Without going into great detail as to the circumstances that led up to this incident, piping handling liquid propane in a propane deasphalting (PDA) unit ruptured. The location of the rupture was in a section of isolated piping that had been abandoned in place several years prior. A valve, intended to isolate the active flow of liquid propane from the abandoned-in-place piping, had been unknowing left partially open due to an obstruction inside the valve. Water had gradually seeped in past the valve seat over the years and being heavier than the liquid propane, settled at a low-point control station where it eventually froze during a cold period. The expanding ice inside the pipeline subsequently cracked the pipe. When the temperature outside began to warm, the ice thawed allowing liquid propane to escape from the active pipeline, through the partially closed valve, and out the now substantial crack. The resultant cloud of propane gas drifted toward a boiler house where it found an ignition source. The flame of the ignited gas cloud tracked back toward its source where the impending shockwave from the explosion ripped apart piping attached to the PDA extractor columns causing ignited propane to erupt from one of the now opened nozzles on the column at such a velocity as to create a jet fire.

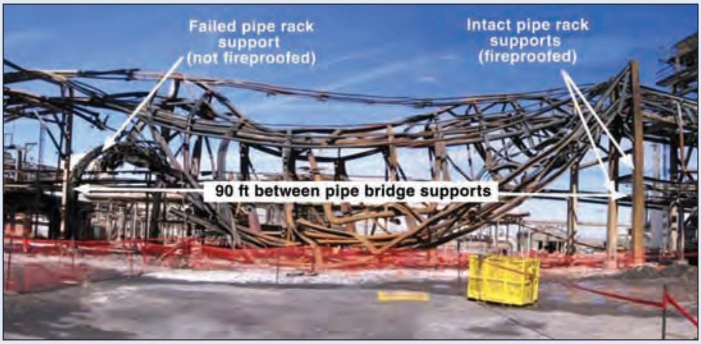

**FIGURE 1.** A collapsed pipe rack as a result of heat from a jet flame

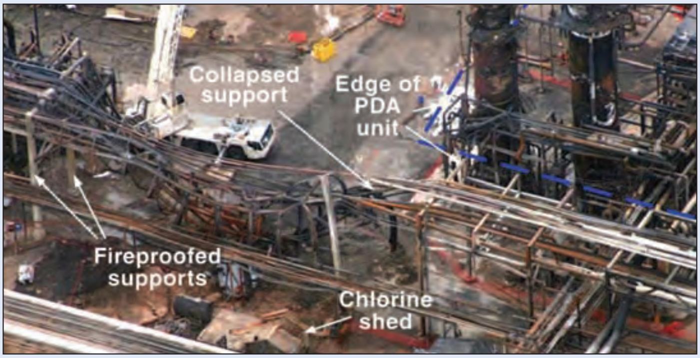

**FIGURE 2.** The same collapsed pipe rack as Figure 1 seen from above

The ensuing jet fire, which is a blow-torch like flame, discharged toward a main pipe rack approximately 77 ft away, engulfing the pipe rack in the jet fire. As the temperature of the non-fire-proofed structural steel of the pipe rack reached its plastic range and began to collapse in on itself, the piping in the rack, which contained additional flammable liquids, collapsed along with it (Figure 1).

Due to the loss of support and the effect of the heat, the pipes in the pipe rack, unable to support its own weight, began to sag. The allowable bending load eventually being exceeded from the force of its unsupported weight, the rack piping ruptured spilling its flammable contents into the already catastrophic fire. The contents of the ruptured piping, adding more fuel to the fire, caused the flames to erupt into giant fireballs and thick black smoke.

The non-fire-proofed support steel (seen on the left in Figure 1 and on the right in Figure 2) was actually in compliance with API recommendations. Those recommendations can be found in Publication 2218 — Fireproofing Practices in Petroleum and Petrochemical Processing Plants; API Publications 2510 — Design and Construction of LPG Installations; and 2510A — Fire-Protection Considerations for the Design and Operation of Liquefied Petroleum Gas (LPG) Storage Facilities. In these issues of the publications it was recommended that pipe-rack support steel within 50 ft of an LPG vessel be fire proofed. The collapsed support steel was approximately 77 ft from the extractor columns, which is beyond the 50-ft recommended distance.

While the EOR was in compliance with the governing code, with regard to fire proofing, there may have been a degree of complacency in defaulting to that minimum requirement. This goes back to a point made earlier in which it was said that industry standards are not intended to be design manuals. They instead provide, "…the minimum requirements necessary to integrate safety into the design, fabrication, inspection, installation, and testing of piping systems…" Proprietary circumstances make it the imperative responsibility of the EOR or the owner to make risk assessments based on specific design conditions and go beyond the minimum requirements of an industry code or standard when the assessment results and good engineering practices dictate. ❑

into a possible catastrophic event, can then be the result of inadequate design requirements that extend beyond the piping itself.

While this discussion touches only on piping issues, know that this is only a part of the overall integration of safety into the design of a facility that handles hazardous fluids. What follows are recommended piping design considerations that are intended to substantially reduce the risk of the onset of fire and its uncontrollable spread throughout a facility. In discussing the spread of fire, it will be necessary to include discussion regarding the needs for disciplines other than piping, namely fire proofing of structural steel.

### General codes and standards

From a fire-safety standpoint, some requirements and industry regulations are stipulated in the International Fire Code (IFC), published by the International Code Conference (ICC) under IFC 3403.2.6.6. There are also requirements by the National Fire Protection Assn. (NFPA) under NFPA 1 and NFPA 30. Test requirements for fire-rated valves can be found under API 607 — "Fire Test for Soft Seated Quarter Turn Valves." Starting with the 4th edition of this API standard, it was added that, among other things, the tested valve has to be operated from fully closed to fully open after the fire test. Prior to the 4th edition a soft-seated fire-rated valve had to only remain sealed when exposed to fire without having to be operated, or rotated. Additional fire test requirements can be found as published by the BSI Group (formerly known as British Standards Institution) as BS-6755-2 "Testing of Valves. Specification for Fire Type-Testing Requirements," and FM Global FM-7440 "Approval Standard for Firesafe Valves."

With exception to the specific requirements covered in the valve testing standards, the codes and standards mentioned above provide generalized requirements that touch on such key aspects of safety as relative equipment location, mass volume versus risk, electrical classifications, valving, and so on. They cannot, and they are not intended to provide criteria and safeguards for every conceivable situation. Designing safety into a particular piping system containing a hazardous liquid goes beyond what should be expected from an industry-wide code or standard and falls to the responsibility of the owner or EOR. As ASME B31.3 states in its introduction, "The designer is cautioned that the code is not a design handbook; it does not do away with the need for the designer or for competent engineering judgment."

When designing piping systems to carry hazardous liquids, the design basis of a project or an established protocol for maintenance needs to incorporate a mitigation strategy against two worse-case scenarios: (a) A leak at a pipe joint containing a hazardous liquid, and (b) The rupture or loss of containment, during a fire, of surrounding hazardous piping systems, not otherwise compromised that would add fuel to the fire.

The occurrence of those two failures, one initiating the incident and the other perpetuating and sustaining the incident, can be minimized or eliminated by creating a design basis that provides the following:

- Added assurance against the potential for joint failure
- Added assurance of containment and control of a hazardous liquid during a fire
- Safe evacuation of a hazardous liquid from the operating unit under distress

## Fire prevention through design

***Piping joints.*** When designing piping systems to contain hazardous liquids, one of the key objectives for the design engineer should be taking the necessary steps to minimize the threat of a leak, steps beyond those typically necessary in complying with the minimum requirements of a code. There are certainly other design issues that warrant consideration, and they will be touched on much later. However, while the pipe, valves, and instrumentation all have to meet the usual criteria of material compatibility, pressure, and temperature requirements there are added concerns and cautions that need to be addressed.

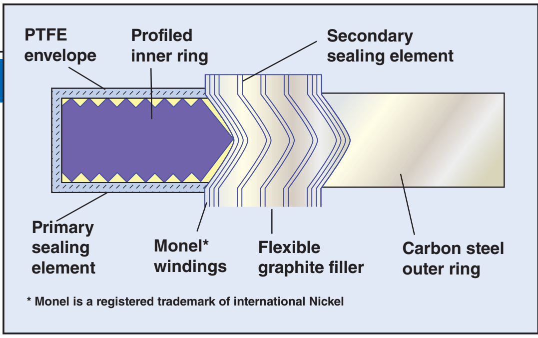


**FIGURE 3. If flanged joints are necessary, it is suggested that fire-safe spiral-wound type gaskets with graphite filler be specified**

Those concerns and cautions are related to the added assurance that hazardous liquids will stay contained within their piping system during normal operation and for a period of time during a fire as expressed in such standards as API-607, FM-7440, and BS-6755-2. Designing a system, start to finish, with the intent to minimize or eliminate altogether the potential for a hazardous chemical leak will greatly help in reducing the risk of fire. If there is no fuel source there is no fire. In the design of a piping system, leak prevention begins with an assessment of the piping and valve joints.

There are specified minimum requirements for component ratings, examination, inspection, and testing that are required for all fluid services. Beyond that, there is no guidance given for fire safety with regard to the piping code other than a statement in B31.3 Para. F323.1 in which it states, in part: "The following are some general considerations that should be evaluated when selecting and applying materials in piping: (a) the possibility of exposure of the piping to fire and the melting point, degradation temperature, loss of strength at elevated temperature, and combustibility of the piping material under such exposure, (b) the susceptibility to brittle failure or failure from thermal shock of the piping material when exposed to fire or to fire-fighting measures, and possible hazards from fragmentation of the material in the event of failure, (c) the ability of thermal insulation to protect piping against failure under fire exposure (for example, its stability, fire resistance, and ability to remain in place during a fire)."

The code does not go into specifics on this matter. It is the engineer's responsibility to raise the compliance-level requirements to a higher degree where added safety is warranted and to define the compliance criteria in doing so.

Joints in a piping system are its weak points. All joints, except for the full penetration buttweld, will de-rate a piping system to a pre-determined or calculated value based on the type of joint. This applies to pipe longitudinal weld seams, circumferential welds, flange joints and valve joints such as the body seal, stem packing, and bonnet seal, as well as the valve seat. For manufactured longitudinal weld seams, refer to ASME B31.3 Table A-1B for quality factors ($E$) of the various types of welds used to manufacture welded pipe. The quality factor is a rating value, as a percentage, of the strength value of the longitudinal weld in welded pipe. It is used in wall thickness calculations as in the following equations for straight pipe under internal pressure:

$$t = \frac{PD}{2(SEW + Py)} \quad (1)$$

$$t = \frac{P(d + 2c)}{2\ SEW - P(1 - y)} \quad (2)$$

Where:

$c$ = sum of mechanical allowances
$D$ = outside dia. of pipe
$d$ = inside dia. of pipe
$E$ = quality factor from Table A-1A and A-1B
$P$ = internal design gage pressure
$S$ = stress value for material from Table A-1
$t$ = pressure design thickness
$W$ = weld-joint strength-reduction factor
$y$ = coefficient from Table 304.1.1

Also found in Para. 304 of B31.3 are wall thickness equations for curved and mitered pipe.

With regard to circumferential welds, the designer is responsible for assigning a weld-joint reduction factor ($W$) for welds other than longitudinal welds. What we can do, at

## INCIDENT NO. 2: FORMOSA PLASTICS CORP., POINT COMFORT, TEX., OCT. 6, 2005

A trailer being towed by a forklift operator down a pipe rack alley in the Olefins II operating unit of Formosa's Point Comfort facility attempted to back the trailer up into an open area between pipe rack support columns in an effort to turn the rig around. When the operator, in the process of pulling back into the pathway, began to pull forward the trailer struck a protruding 2-in. blow-down valve on a vertically mounted Y-strainer that was connected to a 4-in. NPS liquid propylene line subsequently ripping the valve and nipple from the strainer (Figure 4). Liquid propylene under 216 psig pressure immediately began discharging into a liquid pool from the 2-in. opening and partially vaporizing into a flammable cloud.

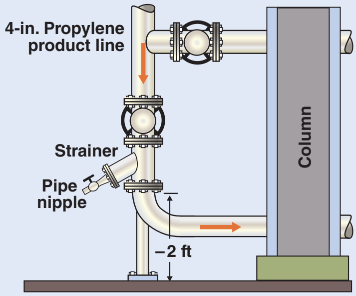


**FIGURE 4.** The impact point (left) showing the damaged Y-strainer

The flammable cloud eventually found an ignition source, ignited and exploded, in-turn igniting the pool of liquid propylene. The fire burned directly under the pipe rack and an attached elevated structure containing process equipment and piping. About 30 min into the event, non-fire-proofed steel sections of the pipe rack and the elevated structure containing process equipment collapsed (Figure 5). The collapse caused the rupture of equipment and additional piping containing flammable liquids, adding more fuel to an already catastrophic fire. The flare header was also crimped in the collapse and ruptured, causing flow that should have gone to the flare stack to be discharged into the heart of the fire. The fire burned for five days.

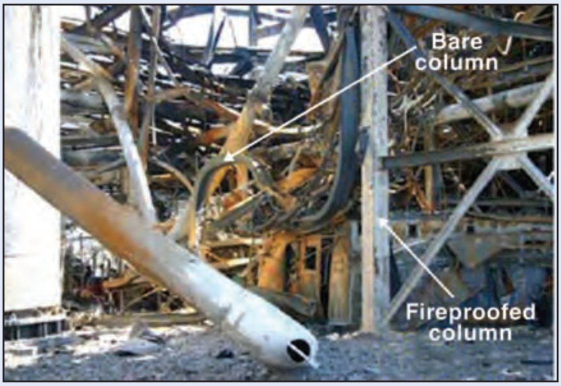


**FIGURE 5.** Collapse of non-fire-proofed structural steel

Again, as in Incident No. 1, you can see in Figure 5 the result of insufficient fire proofing of steel beams and columns in close proximity to process units. And fire protection does not apply only to vertical columns. As you can see, it is not sufficiently effective to have the vertical columns protected while the horizontal support steel is left unprotected and susceptible to the heat from a fire.

Another key factor in the Formosa fire was the ambiguous decision by the designer to orient the Y-strainer blow-down in such a position of vulnerability. While there is absolutely nothing wrong with installing the Y-strainer in the vertical position, as this one was, they are normally installed in a horizontal position with the blow-down at the bottom, inadvertently making it almost impossible to accidentally strike it with enough force to dislodge the valve and nipple.

However, orienting the blow-down in such a manner, about the vertical axis, should have initiated the need to evaluate the risk and make the determination to rotate the blow-down about its vertical axis to a less vulnerable location, or to provide vehicle protection around the blow-down in the form of concrete and steel stanchions. Both of these precautionary adjustments were overlooked.

The plant did perform a hazard and operability study (HAZOP) and a pre-startup safety review (PSSR) of the Olefins II operating unit. In the CSB report, with regard to process piping and equipment, it was stated that, "During the facility siting analysis, the hazard analysis team [Formosa] discussed what might occur if a vehicle (for instance, fork truck, crane, man lift) impacted process piping. While the consequences of a truck impact were judged as "severe," the frequency of occurrence was judged very low (that is, not occurring within 20 years), resulting in a low overall risk rank [The ranking considered both the potential consequences and likely frequency of an event]. Because of the low risk ranking, the team considered existing administrative safeguards adequate and did not recommend additional traffic protection." ❑

least for this discussion, is to provide, as a frame of reference, some quality rankings for the various circumferential welds based on the stress intensification factor (*SIF*) assigned to them by B31.3. In doing so, the full penetration buttweld is considered to be as strong as the pipe with an *SIF* = 1.0. The double fillet weld at a slip-on flange has an *SIF* = 1.2. The socketweld joint has a *SIF* = 2.1. Any value in excess of 1.0 will de-rate the strength of the joint below that of the pipe. With that said, and assuming an acceptable weld, the weld joint, and particularly the full penetration buttweld, is still the joint with the highest degree of integrity. In a fire, the last joint type to fail will be the welded joint.

The threaded joint has an *SIF* = 2.3 and requires a thread sealant applied to the threads, upon assembly, to maintain seal integrity. With flame temperatures in a fire of around 2,700–3,000°F the thread sealant will become completely useless if not vaporized, leaving bare threads with no sealant to maintain a seal at the joint.

The flange-joint-sealing integrity, like the threaded joint, is dependent upon a sealant, which, unlike the threaded joint, is a gasket. Flange bolts act as springs, providing a constant live load so long as all things remain constant. Should the gasket melt or flow due to the heat of a fire, the initial tension that was given the bolts when the joint was assembled will be lost. Once the gasket has been compromised the sealing integrity of the joint is gone.

Knowing that the mechanical type threaded and flange joints are the weak points in a piping system, and the primary source for leaks, it is suggested that their use be minimized to the greatest extent possible. Consider the following design points:

- Do not specify flange joints solely for installation purposes
- Specify flange joints only where required for equipment connections and for break-out spools

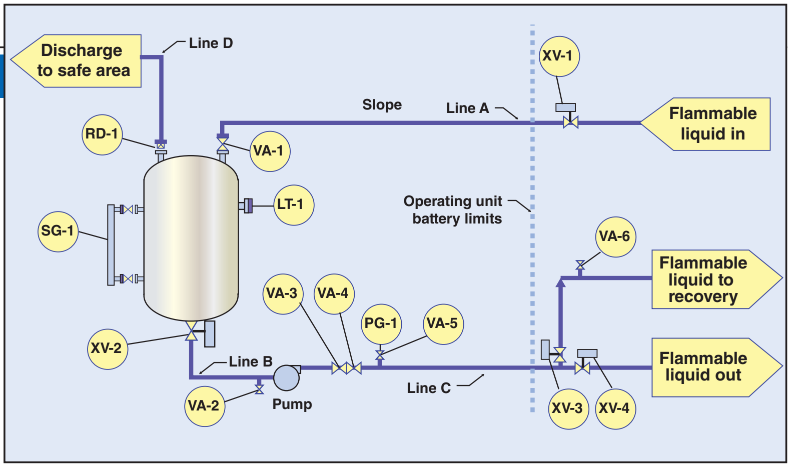


**FIGURE 6.** A simplified P&ID used in the discussion about process systems

- If a lined pipe system is required, use the type requiring the liner to be fused, a coupling installed and one that is suitable for multi-axis bending

Threaded joints should be limited to instrument connections and then only if the instrument is not available with a flange or welded connection. If a threaded connection is used, it should be assembled without thread compound then seal-welded. This may require partial dismantling of the instrument to protect it from the heat of the welding process.

It is recommended that piping systems be welded as much as possible and flanged joints be minimized as much as possible. That includes using welded end valves and inline components where possible. If flanged joints are necessary for connecting to equipment nozzles, flanged valves, inline components, or needed for break-out joints, it is suggested that a spiral-wound type gasket with graphite filler be specified. This material can withstand temperatures upwards of 3,000°F. There are also gasket designs that are suitable for when a fluoropolymer material is needed for contact with the chemical, while also holding up well in a fire. These are gaskets similar in design to that shown in Figure 3.

***Valves.*** A fire-rated valve meeting the requirements of API 607 (Fire Test for Soft Seated Quarter Turn Valves) is designed and tested to assure the prevention of fluid leakage both internally along the valve's flow path, and externally through the stem packing, bonnet seal, and body seal (where a multi-piece body is specified). Testing under API 607 subjects a valve to well defined and controlled fire conditions. It requires that after exposure to the fire test the valve shall be in a condition that will allow it to be rotated from its closed position to its fully open position using only the manual operator fitted to the test valve.

Quarter turn describes a type of valve that goes from fully closed to fully open within the 90 deg rotation of its operator. It includes such valve types as ball, plug, and butterfly with a valve seat material of fluoropolymer, elastomer, or some other soft, non-metallic material.

Standards such as FM-7440 and BS-6755-2, touched on earlier, apply to virtually any valve type that complies with their requirements. Under the FM and BS standards, valve types such as gates, globes, and piston valves with metal seats can also make excellent fire-rated valves when using a body and bonnet gasket and stem packing material similar in temperature range to that of a graphite or graphite composite.

***Process systems.*** At the onset of a fire within an operating unit, initially unaffected process piping systems should not be a contributor to sustaining and spreading what is already a potentially volatile situation. There are basic design concepts that can be incorporated into the physical aspects of a process system that will, at the very least, provide precious time for operators and emergency responders to get the situation under control. In referring to the simplified piping and instrumentation diagram (P&ID) in Figure 6, there are seven main points to consider:

1. Flow supply (Line A), coming from the fluid's source outside the operating unit, needs to be remotely shut off to the area that is experiencing a fire
2. The flow path at the systems use point valves (VA-1) needs to remain open
3. The flow path at drain and vent valves (VA-2) needs to remain sealed
4. The external path through stem packing and body seals needs to remain intact during a fire
5. The bottom outlet valve (XV-2) on a vessel containing a flammable liquid should have an integral fusible link for automatic shut-off, with its valve seat, stem packing and body seals remaining intact during a fire
6. Pipeline A should be sloped to allow all liquid to drain into the vessel
7. The liquid in the vessel should be pumped out to a safe location until the fusible link activates, closing the valve. There should be an interlock notifying the control room and shutting down the pump

Those seven points, with the help of the P&ID in Figure 6, are explained as follows:

***Point 1.*** The supply source, or any pipeline supplying the operating unit with a flammable liquid, should have an automated, fire-rated isolation valve (XV-1) located outside the building or operating unit area and linked to the unit's alarm system with remote on/off operation (from a safe location) at a minimum.

***Point 2.*** Any point-of-use valve (VA-1) at a vessel should remain open during a fire. The area or unit isolation valve (XV-1) will stop further flow to the system, but any retained or residual fluid downstream of the automatic shut-off valve needs to drain to the vessel where the increasing overpressure, due to heat from the fire, will be relieved to a safe location, such as a flare stack, through RD-1. If the Valves, XV-1 and VA-1, are closed in a fire situation the blocked-in fluid in a heated pipeline will expand and potentially rupture the pipeline; first at the mechanical joints such as seals and packing glands on valves and equipment, as well as flange joints, and then ultimately the pipe itself will rupture (catastrophic failure). During a fire, expanding liquids and gases should have an unobstructed path through the piping to a vessel that is safely vented.

***Point 3.*** Valves at vents and drains (VA-2 & VA-6) need to be fire-rated and remain closed with seals and seat intact for as long as possible during a fire.

## INCIDENT NO. 3: BP REFINERY, TEXAS CITY, TEX., JULY 8, 2005

In the design layout of a duplex heat-exchanger arrangement (Figure 7) in the resid-hydrotreater unit of the BP Refinery in Texas City, Tex., the designer duplicated the fabrication dimensions of the 90-deg fabricated elbow-spool assemblies shown in Figure 7 as Elbows 1, 2, and 3. While the pipe sizes and equipment nozzle sizes were the same, permitting an interchangeability of the fabricated elbow spool assemblies, the service conditions prohibited such an interchange.

The shell side conditions on the upstream side (at Elbow 1) were 3,000 psig at 400°F. The shell side conditions on the downstream side (at Elbow 3) were 3,000 psig at 600°F. The intermediate temperature at Elbow 2 was not documented. In the initial design, the material for Elbow 1 was specified as carbon steel, Elbow 3 was specified as a 1 - 1/4 chrome/moly alloy. The reason for the difference in material of construction (MOC) is that carbon steel is susceptible to high temperature hydrogen attack (HTHA) above ~450°F at 3,000 psig, therefore the chrome/moly alloy was selected for the higher temperature Elbow 3.

At 3,000 psig and temperatures above 450°F hydrogen permeates the carbon steel and reacts with dissolved carbon to form methane gas. The degradation of the steel's tensile strength and ductility due to decarburization, coupled with the formation of methane gas creating localized stresses, weakens the steel until it ultimately fatigues and ruptures.

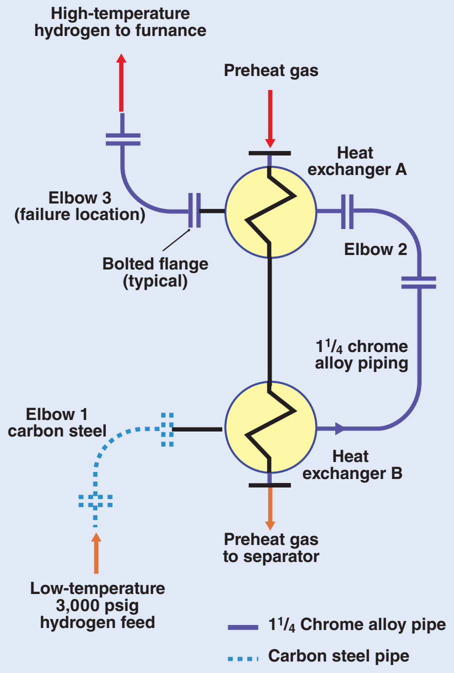


**FIGURE 7.** Heat exchanger flow diagram

**FIGURE 8.** Severed 8-in. NPS hydrogen piping

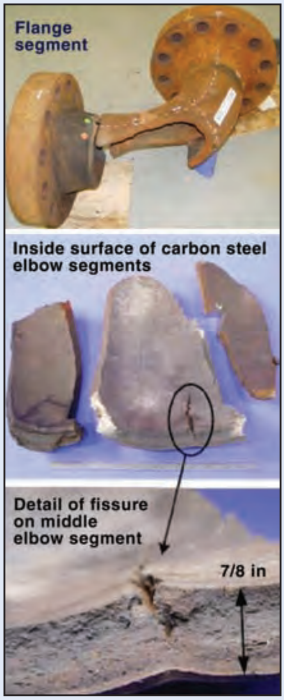


**FIGURE 9.** Fragments of the failed 8-in. NPS carbon-steel spool

In January 2005, scheduled maintenance was performed on the heat exchanger assembly. The piping connected to the heat exchangers was dismantled and stored for the next 39 days. After maintenance was completed, the piping was retrieved from storage and reinstalled.

The elbows of different material were not marked as such and the maintenance contractor was not warned of the different MOC for the elbows. Elbows 1 and 3 were unknowingly installed in the wrong locations. On July 8, 2005, approximately five months after re-installing the piping around the heat exchangers, the elbow in the #3 position catastrophically failed as shown in Figure 8.

As you can see in Figure 9 the carbon steel, after becoming progressively weakened by HTHA, fractured on the inside of the pipe and catastrophically failed. The incident injured one person in operations responding to the emergency and cost the company $30MM.

The one thing you can take away from this incident is: *Do not dimensionally replicate piping spools or assemblies of different materials.* The other underlying, but significant component you can also take away is this: In the initial design of a plant facility the engineer of record will routinely hold formal design reviews that will include all key personnel with vested interest in the project. In doing so, include, among the attendees, key operations and management plant personnel from one of the owner's operating facilities, if available. These individuals typically bring a lot of insight and knowledge to a review. Whereas the designers may not have the wherewithal to think along the lines of issues that might pertain to a facility turnaround, the plant personnel will. These are issues that they normally think long and hard about. Make use of this resource. ❑

***Point 4.*** During a fire, another source for valve leakage is by way of stem packing and body seal, as mentioned earlier. Leakage, at these seal points, can be prevented with valves that are not necessarily fire-rated, but contain stem packing and body seal gasket material specified as an acceptable form of graphite (flexible graphite, graphoil and so on). This is a fire-safe material which is readily available in non-fire-rated valves.

***Point 5.*** The valve on the bottom of the vessel should be fire-rated with a fusible link or a fail closed position. Relying on an air or electric operated valve actuator may not be practical. A fusible link is most certainly needed on a manually operated valve. The contents of a vessel containing a hazardous liquid needs to get pumped to a safe location during a fire until such time as the fusible link is activated, closing the tank bottom valve, or the pump fails. All valved gage and instrument connections (SG-1) mounted on a vessel should have a graphite-type stem packing and body-seal-gasket material at a minimum. Flange gaskets at these gage and instrument connections should be of a spiral-wound fire-safe gasket type similar to those mentioned earlier. Specialty tank-bottom valves (XV-2) should be given special consideration in their design by considering a metal-to-metal seat, or a piston valve design along with fire-rated seal material.

***Point 6.*** As mentioned in Point 2, the residual fluid in Line A, after flow has been stopped, should be drained to the vessel. To help the liquid drain, the pipeline should be sloped toward the vessel. The intent, as mentioned above, is to prevent sections of any pipeline that do not contain a relief device from being blocked and isolated during a fire. If the piping system for flammable fluid service is designed properly, the contents will be able to drain or expand into a vessel where over-pressurization can be relieved and safely vented.

***Point 7.*** It will be necessary to evacuate as much of the hazardous fluid as possible from tanks and vessels in the fire area to a safe location. The pump-out should continue until there is inadequate pump suction head, or until the fusible link on XV-2 is activated. At that time the pump interlocks would shut down the pump.

With regard to tank farms, the following is a suggested minimum consideration for a safe design: Drain valves should be of a fire-rated type. Tank outlet valves should be of a fire-safe type with a fusible link. Tank nozzles used for gages or instrument connections should have, at a minimum, valves containing stem packing and seal gasket material specified as an acceptable form of graphite, as mentioned above, or some other fire-safe material. Gaskets used at nozzle flange joints should be a fire-safe gasket similar to the spiral wound gaskets mentioned earlier or the gasket shown in Figure 3.

Inline valves in piping downstream of the tank outlet valve, such as pump transfer lines and recirculation lines, do not necessarily need to be fire-rated, but should have stem packing and seal gasket material that is fire-safe as mentioned earlier.

Situations will arise that do not fall neatly into what has been described above. If there is any doubt with regard to valving then default to a fire-rated valve. Each piping system identified as needing to be fire-safe should be designated as such. Where individual fire-safe valves are to be strategically located in a system, they should be designated on their respective P&IDs either by notation or through the assigned pipe material specification. The pipe-material specification should be indicated on each pipeline of the P&ID. The specification itself should therefore be descriptive enough for the designer to know which valve to apply at each location.

## Lessons learned from incidents

While this particular discussion is specific to piping leaks and joint integrity it bares touching on a few subjects that are integrally associated with piping safety: pipe rack protection, protecting piping from vehicle traffic, and designing for disaster (HAZOP).

In Incident Number 1 (box, p. 37), the onset of a fire that might otherwise have been quickly controlled becomes a catastrophic event because piping mounted on the unprotected structural steel of a pipe rack, outside the extent of the initial occurrence, becomes collateral damage adding more fuel to the fire causing it to sustain itself, increase in intensity and continue to spread.

In Incident Number 2 (box, p. 39), an unprotected and protruding pipeline component (Y-strainer) is damaged, causing a major leak that operating personnel were unable to stop. The ensuing fire lasted for five days.

In Incident Number 3 (box, p. 41), two dimensionally identical spool pieces were designed for a system in which the two were fabricated from different materials because their service conditions were very different. It can only be assumed that this was an erroneous attempt at trying to achieve duplication of pipe spools in an effort to assist the fabricator in their productivity of pipe fabrication. Instead it ultimately caused injury to one person and cost the plant owner $30MM. ■

*Edited by Gerald Ondrey*

## Author


**W. M. (Bill) Huitt** has been involved in industrial piping design, engineering and construction since 1965. Positions have included design engineer, piping design instructor, project engineer, project supervisor, piping department supervisor, engineering manager and president of W. M. Huitt Co. (P.O. Box 31154, St. Louis, MO 63131-0154; Phone: 314-966-8919; Email: wmhuitt@aol.com; URL: www.wmhuitt.com), a piping consulting firm founded in 1987. His experience covers both the engineering and construction fields and crosses industrial lines to include petroleum refining, chemical, petrochemical, pharmaceutical, pulp and paper, nuclear power, biofuel, and coal gasification. He has written numerous specifications, guidelines, papers, and magazine articles on the topic of pipe design and engineering. Huitt is a member of ISPE (International Society of Pharmaceutical Engineers), CSI (Construction Specifications Institute) and ASME (American Society of Mechanical Engineers). He is a member of three ASME-BPE subcommittees, several task groups, an API task group, and sits on two corporate specification review boards.

# Containing Fugitive Emissions

## Practical ways to seal valve stems and prevent unwanted emissions

**Jim Drago**
Garlock Sealing Technologies

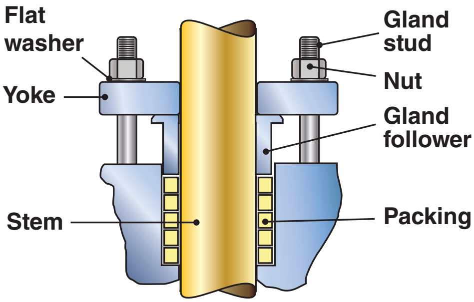


**FIGURE 1.** This cross-sectional view shows a typical valve-stem sealing assembly

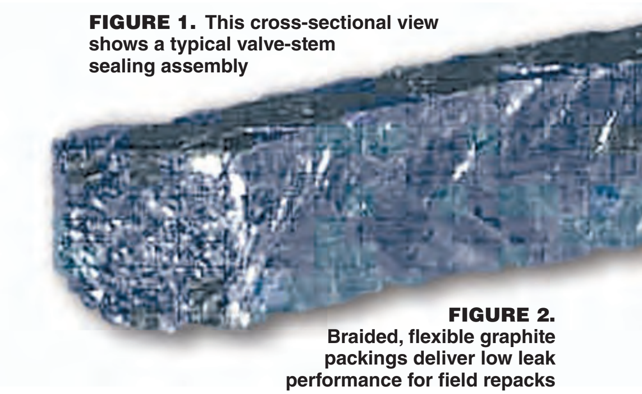

**FIGURE 2.** Braided, flexible graphite packings deliver low leak performance for field repacks

Containing fugitive emissions of volatile organic compounds (VOCs) and hazardous air pollutants (HAPs) is a challenge to the chemical process industries (CPI). It has been estimated that these industries account for half of all fugitive emissions, and 60% of these emissions are the result of valve stem leaks. In addition to environmental benefits, effectively containing these emissions can yield significant operational and economic benefits and avoid punitive penalties for non-compliance with regulatory standards. If cap-and-trade or carbon-tax programs become law, then reducing emissions below mandated levels could yield carbon credits or reduced tax liabilities. Overall, emission reduction improves operating efficiency and creates a safer, more productive workplace.

This article describes how to effectively seal valve stems, including leak detection and repair (LDAR); various types of sealing solutions, their advantages and limitations; performance standards and testing; and proper installation.

### Environmental impact

VOCs and HAPs are major contributors to ground-level ozone, a significant component in smog, which can cause respiratory illnesses. Some VOCs and HAPs are known or suspected carcinogens. The U.S. Environmental Protection Agency (EPA) prescribes proactive LDAR programs, including identifying leaking components, comparing leakage levels to compliance standards, making the necessary repairs, ongoing monitoring and measurement, recording and maintaining data, taking corrective actions, training and audits. These programs are costly and time consuming, and involve thousands of plant components, such as valve stems, flanged-joints, pump seals, pressure relief devices, end connections and others. Plant personnel devote much time and effort to gathering information, maintaining databases and generating the requisite reports, all for the ultimate objective of stopping leaks.

To avoid leaks in the first place, the EPA encourages the use of low-leak valve and packing technologies. Current consent decrees are giving attention to the most prevalent method of controlling valve stem emissions — compression packing (Figure 1).

### Valve stems

Studies have indicated that leaking valve stems are by far the single largest source of fugitive emissions in processing plants. These emissions can be controlled by following simple guidelines that take into account the valve and its service conditions, the seal supplier's recommendations, proper seal installation and ongoing performance monitoring.

Obtaining clear input on the type of valve to be sealed and its mechanical condition is the logical starting point. The most-effective sealing solution depends on whether the valve is occasionally actuated, such as a manually operated gate valve, or a continuously actuated control valve. Poorly maintained equipment can cause stem packings to fail, so it is important to inspect the physical condition of the valve for damage to the gland studs or stem, which if bent or gouged can push into or tear the packing.

Next considerations include the temperature, media and pressure to which the valve seal will be subjected, as well as the level of sealing performance required to comply with federal, state and local regulations, consent decrees and company standards. It should be noted that while federal regulations may require seal performance with a maximum leakage of 10,000 ppm, most states and consent decrees mandate 500 ppm and lower. Some local air-quality-management districts may require levels as low as 250 ppm.

### Sealing types

Different types of seals have different performance attributes in terms of valve actuation force; interaction of axial compression to radial expansion of the packing; friction; emission level; and the ability to retain and adjust a seal for compliance. There are a number of viable choices for valve stem seals, notably die-formed flexible graphite,

**Circle 19 on p. 62 or go to adlinks.che.com/29251-19**

| TABLE 1. SEALING TYPES | | |
|---|---|---|
| Seal Type | Description | Attributes |
| Die-formed flexible graphite | • Flexible graphite with a minimum carbon content of 95% is die-formed into rings with braided carbon or graphite yarn end-rings<br>• The die-formed rings are flat and come in various densities. Higher density rings are used for higher service pressures<br>• Temperature capability to 850°F in atmosphere and 1,200°F in steam; pressure capability to 4,000+ psig<br>• Usually capable of 500-ppm leak performance | • This method has been providing adequate emission performance for over 30 years, but may not attain the low leak rates demanded by the most stringent air-quality-management districts, consent decrees and standard performance specified by plant end users<br>• Rings are made for a specific valve stem and box sizes, and may require adjustment to obtain and maintain low emission results. Multiple-step installation required |
| Braided flexible graphite (Figure 2) | • 95%+ carbon purity, usually with proprietary yarn treatment<br>• Wire reinforcement of the flexible graphite yarn is common<br>• Temperature capability to 850°F in atmosphere, 1,200°F in steam; pressures to 4,500 psig<br>• Capable of <500 ppm and <100 ppm performance | • Introduced in the 1990s, it provides superior emissions performance<br>• One size braid can be used to pack many different sizes of valves, but may require adjustment at startup to obtain low emission results<br>• Multiple-step installation; easy field replacement |
| Engineered sets (Figure 3) | • Combination of die-formed flexible graphite rings of various geometries and densities and braided yarn or braided flexible graphite yarn packings<br>• Good to 850°F in atmosphere, 1,200°F in steam and pressures of 10,000 psig<br>• Capable of <500 ppm and <100 ppm performance | • Some types date to the emission demands of California 1970s — the first clean air laws<br>• Superior emission performance<br>• Sets are made to the specific valve stem and box sizes<br>• Some feature simpler installation procedures to compress the set<br>• Engineered sets are preferred by OEM valve manufacturers wanting low emission performance with assembly line speed of installation |
| Bellows sealed valves | • Metal bellows seal incorporated into the valve design. Packing type seals are used as secondary seals<br>• Temperature and pressure capabilities depend on bellows metallurgy, design and construction; should match the pressure class and material rating of the valve | • Virtually zero emissions<br>• High cost at multiple times that of a standard packed valve<br>• If the seal fails, there is no possibility of adjustment. The valve must be taken off-line and rebuilt or replaced<br>• In some cases elongated valve bonnets are required to accommodate the bellow. Space can be an issue |
| Live loading (Figure 4) | • Disc spring (Belleville) washers are compressed on the gland follower under the gland stud nuts<br>• Temperature and pressure capabilities depend on the type of seal used; live loading does not enhance these ratings | • Can be used with any packed valve<br>• Effectively increases the energy in the gland stud bolts. As packing consolidates, there is less degradation of compressive load for better seal maintenance<br>• Live loading represents added expense, but provides some performance enhancement for valves subject to numerous actuations or thermal cycles<br>• A good solution for valves that are difficult to monitor and access for future adjustment<br>• Debate continues regarding its effectiveness since carbon/graphite packings consolidate very little |

braided flexible graphite (Figure 2), engineered seal sets (Figure 3), bellows sealed valves and live-loaded packing sets (Figure 4). Table 1 gives details for these various seal types.

## Performance standards

Two standards for valve seal performance are API 622, "Type Testing of Process Valve Packing for Fugitive Emissions" and ISO 15848, "Industrial Valves — Measurement, Test and Qualification Procedures for Fugitive Emissions — Part 1: Classification System and Qualification Procedures for Type Testing Valves." Introduced in 2006, API 622 provides test methods for fugitive emissions, corrosion and physical characteristics of valve-stem compression packing independent of valve type (Figures 5 and 6). ISO 15848 qualifies the entire valve including its sealing components.

API 622 prescribes only test methodology, whereas ISO 15848 prescribes both test procedure and pass-fail criteria. Other standards include Germany's TA-Luft for qualifying packing and gasket performance, as well as the standards of individual refiners and chemical processing companies. Table 2 provides the basic criteria of API 622 and ISO 15848.

## Proper installation

Just as important as selecting the right seal for a particular valve application is making sure it is installed properly. Correct installation insures more even compression of the packing, which results in better emissions performance

| TABLE 2. A COMPARISON OF PERFORMANCE STANDARDS | | |
|---|---|---|
| **Test Procedure** | **ISO 15848** | **API 622** |
| Media | Helium or methane | Methane |
| Sensing method | Stem seal:<br>Vacuum: Helium<br>Flush: Helium or methane | Modified EPA Method 21 with fixed probe |
| Pressure | 90 psig | 600 psig |
| High temperature | 392°F and 752°F | 500°F |
| Thermal cycles | 7 | 3 |
| Actuation | ≤ 2,500 cycles (on-off valves)<br>≤ 100,000 cycles (control valves) | 1,500 cycles |
| Pass/fail | Class A: ≤ $10^{-6}$ $cm^3/s/m$ of stem diameter<br>Class B: ≤ $10^{-4}$ $cm^3/s/m$<br>Class C: ≤ $10^{-2}$ $cm^3/s/m$ | Agreement of manufacturer and end user |
| Adjustments | Limited number and frequency | Limited |

**FIGURE 3.** Engineered sets are favored by valve builders for low emission performance

**FIGURE 4.** Live loading: Disc spring washers on the gland bolts store energy that can prolong sealing performance

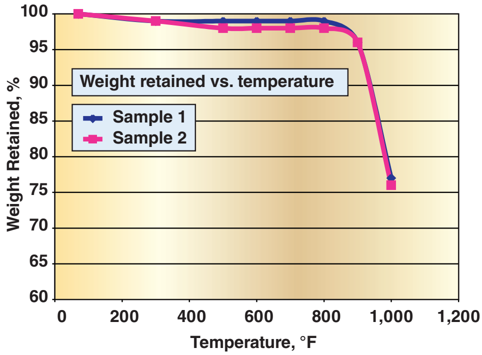


**FIGURE 5.** This graph shows weight retained in the high-temperature oxidizing air environment as specified by API 622

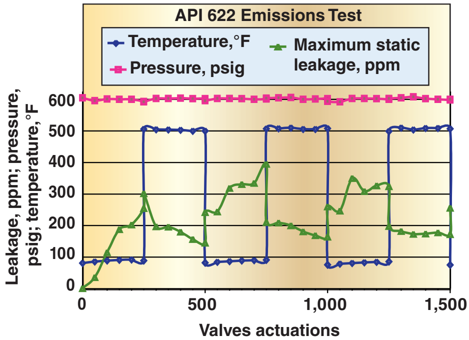


**FIGURE 6.** An emission test chart for API 622 is depicted here

and longer service life. Begin by referring to the manufacturer's installation instructions. Then, remove all the old packing, inspect the stem and stuffing box for any visible defects, and replace or repair any worn or damaged components. Next, measure the stem and bore diameters and stuffing-box depth to calculate the correct packing size and number of rings. If using braid, cut the rings to size using a mandrel the same size as the stem or a packing cutter. The rings are usually installed one at a time.

Special care must be taken not to break die-formed flexible graphite rings when installing them over the stem and into the valve's packing box bore. Installation of engineered sets is governed by manufacturers' specific instructions. After the packing has been installed, check for proper compression and actuate the valve per the manufacturer's instructions. Then make any necessary adjustments and monitor performance against the manufacturer's specifications.

Most manufacturers offer performance guarantees and warranties specific to a particular type of packing. Promising a certain level of emission performance, these guarantees are subject to operating conditions and require installation to the manufacturer's specifications. Most guarantees are dependent on the equipment's condition. If valves are worn and require rework, the packing performance guarantee may be rendered null and void. Most valve-stem seals can wear over time, so service life limitations are typically specified in performance guarantees. It is advisable to get these programs in writing to assess their applicability to plant requirements. The latest consent decrees are requiring documentation verifying the leakage performance of low-leak packings and valves as part of enhanced LDAR programs. Most performance guarantees are also contingent upon the credentials of the installers, which are usually trained and certified by the seal manufacturer. Manufacturer site supervision and accountability may also be available, but at a price.

There are a number of basic criteria for high-performance, low-emission valve stem seals. Emissions should be less than 500 ppm using EPA measuring methods. Since the seal may be exposed to flammable media, it should be fire-safe as verified by API 607, API 589 or similar tests. The valve-stem seal should also be capable of maintaining a seal that is thermally cycled and accommodates reasonable actuation force, which is especially important in control valves.

Following this guidance on sealing selection and installation and engaging the expertise of sealing manufacturers and practicing the elements of proactive LDAR will prepare CPI plants for any type of inspection or audit. The rewards of good sealing selection and practices will manifest themselves in regulatory compliance, increased plant efficiency, improved profitability and a healthy work environment. ■

*Edited by Dorothy Lozowski*

## Author

**Jim Drago**, P.E. is manager of market research for Garlock Sealing Technolgies (Palmyra, N.Y.; Phone: 315-597-3070; Email: jim.drago@garlock.com). He has worked in the areas of sealing technology, field construction engineering and mechanical design for over 30 years. Drago's expertise in sealing technology spans 25 years and includes gaskets, compression packing, oil seals and bearing isolator applications as well as product engineering. He has authored a number of articles on sealing practices, fugitive emissions and leak-detection methods, and has contributed to industry standards and guides for API, ASME, EPRI and STLE. Drago holds a B.S. M.E. from Clarkson University.

# Sealing Technology

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# Sealing systems cut pumping energy costs

*Common installation arrangements for mechanical seals may use more energy than the motor driving the pump, but careful choice of seal support systems can cut costs*

For pump energy efficiency improvements, look to sealing systems; that's the message from the **Fluid Sealing Assn.** (FSA; www.fluidsealing.com) and the **European Sealing Assn.** (ESA; www.europeansealing.com).

A mechanical seal is an energy-efficient device in itself, but the same is not always true of the support systems used to control the operating environment around the seal. FSA research shows that in many applications, thermal energy lost by the seal flush system exceeds the power required to run the pump to which the seal is fitted. As a result, the energy savings that can be achieved from better seal support systems are often far higher than those possible through fitting variable-speed drives or re-sizing pumps.

Recent developments in mechanical seal technology and materials have focused on producing seals that can operate without additional support systems, even in challenging applications. Older seal designs, however, often require a supply of liquid – either once-through or recirculated – to remove heat and prevent contaminants in the process fluid from damaging the seal.

Some of the simpler seal support systems, notably Cool External Flush (API Plan 32) and Cooled Recirculation (API Plan 21), operate by diluting and/or cooling the pumped fluid. As Figure 1 shows, the resulting heat loss can easily be greater than the power required to drive the pump. This wastes energy and reduces the available capacity of plant cooling and heating systems.

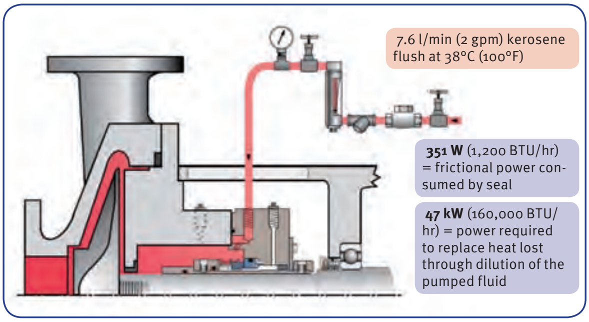


**Figure 1: The 47 kW of heat lost from this seal flush could represent more energy than the pump motor consumes**

Figure 2 shows that API Plans 32 and 21 between them account for more than one-third of seal support systems operating at temperatures above 200°C (400°F). The FSA obtained this information from a survey of 28,000 seal applications.

Figure 2 also shows that some alternative seal support systems use considerably less energy than the wasteful Plans 32 and 21. Plan 23, for instance, is a high-temperature arrangement similar to Plan 21 in that the seal is supplied with liquid that has passed through an external cooler. Whereas in Plan 21 the source of this liquid is the discharge side of the pump, via a flow control orifice, in Plan 23 a pumping ring in the seal chamber does the job with much lower energy consumption. Arrangements using a barrier gas (Plan 74) or a seal that can handle the duty without recirculation (Plan 2) have virtually zero energy requirement.

The study of the energy used by seal support systems falls under the umbrella of Sealing Systems Matter, a project by the FSA and the ESA to help users of sealing devices and systems use less energy, contain emissions, improve safety, and increase equipment reliability by optimizing sealing systems. An important part of the initiative is a focus on life-cycle costs, rather than the initial costs which have traditionally dominated seal selection. ■

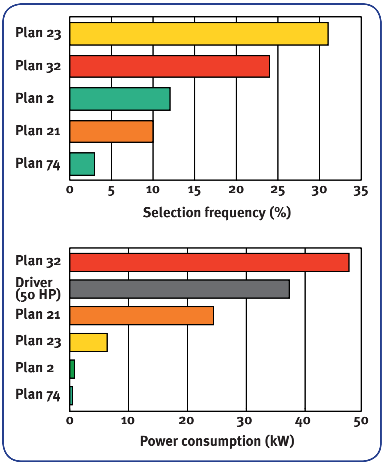


**Figure 2: Some of the most commonly used seal support designs (top) are also some of the most energy-hungry (above)**

# A trade body that is built on quality

The **European Sealing Assn.** (ESA; www.europeansealing.com) has become so confident of the strength of its membership base that it is now prepared to caution member companies who do not pull their weight, says Brian Ellis, the organization's general secretary. "Everyone has technical expertise to contribute, even if they are not doing frontier research," Ellis says. "So we are noting the work that member companies do, and those who take information but don't contribute will not be welcome in future."


ESA European Sealing Association e.V.

Successful sealing with elastomers

An interactive guide to diagnose and prevent seal failure

2010 April

ESA Publication No. 019/10

**Brand new: ESA's interactive guide to O-rings and other elastomeric seals**

The ESA's strategic plan emphasizes activities that individual member companies cannot do on their own, Ellis says: "That's why we spend a lot of time working on laws and standards with bodies like the European Commission."

Another important task is to spread information about sealing technology widely and affordably. One new ESA publication, *Successful sealing with elastomers*, takes the form of an interactive CD. Other publications use print-on-demand technology to eliminate inventory and ensure that buyers always receive the latest version.

The revised and updated ESA website can be viewed in multiple languages and carries discussion forums for ESA members. "As soon as someone hears about a new standard or a piece of legislation which may affect our industries, the information is made available on the forums so that we can discuss it," says Ellis. ■

# Peak performance from this new gasket material

*Flexitallic's Thermiculite gasket material combines peak performance with environmental safety, avoiding some of the drawbacks of graphite*

The search for an effective alternative to traditional mineral fiber material in sheet gaskets has often been an exercise in frustration.

Once-promising graphite has shown mixed results, especially at higher temperatures in oxidizing environments. When the carbon in graphite reacts with atmospheric or process oxygen to form carbon dioxide ($O_2$ (gas) + C(solid) ⇢ $CO_2$ (gas)), oxidation occurs. In addition, naturally occurring impurities cannot be refined from raw graphite, creating another set of performance problems.

Some gasket manufacturers have attempted to compensate by incorporating oxidation-inhibitor additives into their graphite-based products, but these stopgap measures have been effective only at delaying – not eliminating – the eventual effects of time and temperature.

The most promising alternative to traditional mineral fiber materials and graphite has been Vermiculite-based materials. Vermiculite is a hydrated lamellar mineral composed of aluminium-iron magnesium silicate. Unlike the traditional mineral fiber (an aluminosilicate fiber) Vermiculite is a plate structure: non-oxidizing, capable of exfoliating, thermally stable and fire-safe, with broad chemical resistance and a plate-shaped primary particle—all excellent properties for gasket raw materials.

**Flexitallic**, a company with U.S. headquarters in Deer Park, Texas and manufacturing plants in the U.K. and China, has used the remarkable properties of Vermiculite to develop Thermiculite, a gasket material that seals as effectively as traditional mineral fiber materials and more effectively than graphite without negative consequences.

Thermiculite is composed of chemically and thermally exfoliated Vermiculite, simulating the structure of exfoliated graphite with some notable exceptions – it maintains integrity through a wide range of temperatures, from moderate to extreme, and it maintains broad chemical resistance and freedom from oxidation. It is suitable for replacing aramid fiber, glass fiber, carbon fiber, PTFE and graphite in a wide array of applications.

Thermiculite is available in a wide and flexible array of configurations, from spiral-wound, serrated metal and sheet gaskets to braided packing.

**www.flexitallic.com**

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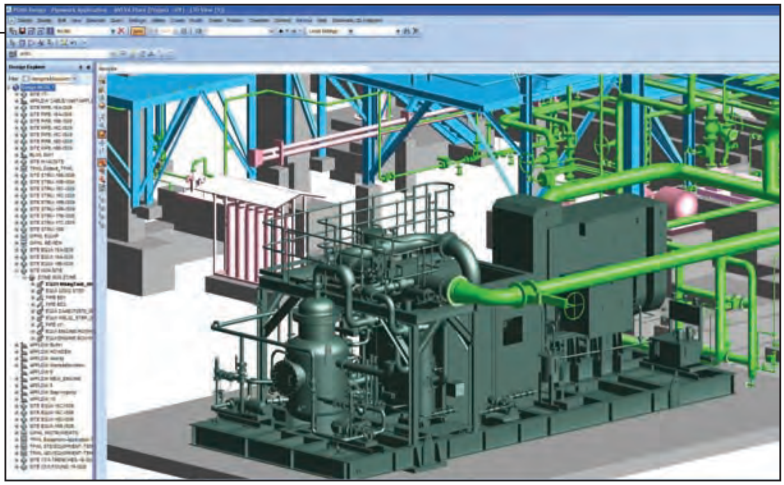


**FOCUS ON**

# Computer Modeling

### This software allows data exchange for 3-D modeling

The Mechanical Equipment Interface product (photo) is designed to allow integration of modeling information between otherwise incompatible three-dimensional (3-D) design systems. In particular, plant piping designers often have to integrate suppliers' equipment models that have been created in a mechanical computer-assisted design (MCAD) system. These model formats are often incompatible with plant design systems, the company says. The Mechanical Equipment Interface product allows bi-directional exchange of three-dimensional models between MCAD systems and plant design systems, such as this company's PDMS. — *Aveva Solutions Ltd., Cambridge, U.K.*
**www.aveva.com**

### Simulate fluidized bed thermodynamics with this software

The Barracuda v14 simulation software (photo) offers 3-D modeling of chemical, thermal and flow dynamics in gas-solid and liquid-solid systems. The latest release includes a new chemistry module for modeling homogeneous and heterogeneous chemical reactions inside fluidized bed reactors. It also is designed to model the release of an entrapped gas or liquid within a solid. Other features of the software include a liquid injection module that simulates liquid spray coating of particles, and a wear model that allows wall wear to be reported on a yearly basis. Barracuda is capable of modeling fluid-catalytic-cracking reactors, circulating-fluidized-bed burners in coal plants, gasification reactors and others in laboratory, pilot and production scale. — *CPFD Software LLC, Albuquerque, N.M.*
**www.cpfd-software.com**

### This process management software adds functionality

Version 7 of TrakSYS process management software has been updated to improve intelligence-based decision making and facilitate realtime data exchange among systems. Updates to the new version are focused on the delivery of personalized, actionable and timely information to those needing it throughout the enterprise. Raw data can be converted to readily useable intelligence by analytics that users are able to configure on personalized "dashboards." — *Parsec Automation Corp., Brea, Calif.*
**www.parsec-corp.com**

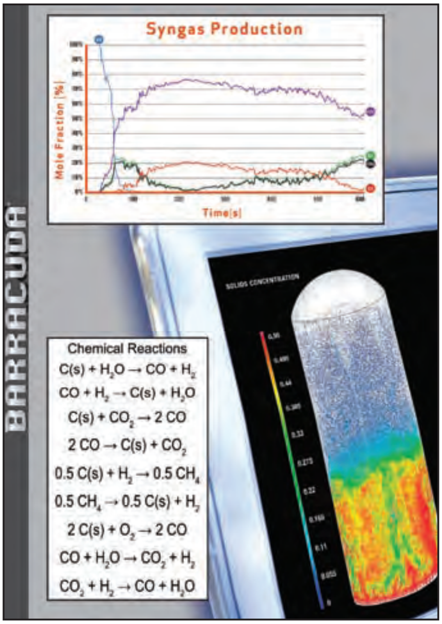
### This MPC algorithm is rewritten for modern software

The DMCX1 model predictive control (MPC) software is a rewrite of a 1990s-era dynamic matrix control (DMC) algorithm. The adjusted process-control algorithm uses modern compilers and software technology, and is ten times faster than previous versions of the modeling software package, the company says. The DMCX1 software contains a "data historian" that exports data to most process watch software packages. — *Cutler Technology, Boerne, Tex.*
**www.cutler-tech.com**

### This software integrates electrical and physical plant design

Substation V8i integrates design tools for electrical systems with those for 3-D building modeling. The software supports key electrical system components, such as electrical schematics, grounding grid, lightning protection and lighting design. The software intra-operates with this company's other software offerings on site design, architectural design and building modeling. The integrated system can replace paper-based workflows and disparate collections of software. The company says its software can reduce electrical system design time by 30%. — *Bentley Systems Inc., Exton, Pa.*
**www.bentley.com**

CPFD Software




### Predict spray system performance with these services

This company offers process-modeling services for predicting the performance of spray systems or fabricated components when actual operating conditions are difficult to replicate in the laboratory. Services offered are computational fluid dynam-

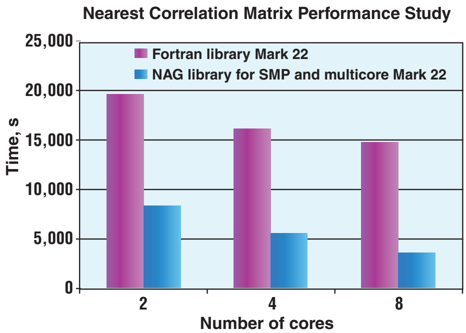
*Note*: For more information, circle the 3-digit number on p. 62, or use the website designation.

ics (CFD), finite element methods (FEM) and fluid structure interaction (FSI). CFD is used to determine how spray performance is affected by gas and liquid flows, gas velocity, temperature, pressure and other operating conditions. Models can determine factors such as evaporation time, spray trajectory, drop size distribution in the gas flow and wall wetting. FEM is used to analyze material suitability for spray injectors, while FSI evaluates the interaction between solid structures and flowing fluid at given conditions. — *Spraying Systems Co., Wheaton, Ill.*
**www.spray.com**

**Use this simulation platform for chemicals research**
The latest version of Materials Studio modeling and simulation platform is said to cut time to solutions in materials and chemical research. Designed for a wide range of applications, including catalysis, polymers and drug development, the updated software features improved parallel codes at every simulation scale, including quantum, atomistic and mesoscale. The company has also added an integrated set of tools for polymer and soft-matter research as well as a wider range of analytical instrument simulations, including Raman spectra simulations. — *Accelrys Software Inc., San Diego, Calif.*
**www.accelrys.com**

**An improved user interface is a highlight of this software version**
Version 2 of this company's object-oriented simulation software features an improved user interface, including a more intuitive scheme for finding and navigating between model components. The new version also has additional tools for debugging and validation of models, and a network licensing capability to allow the system to be used on multiple desktops and across multiple geographic locations. Other added features for Version 2 are an enhanced help function, online videos and an easier way to view full-screen animation. — *Simio LLC, Sewickley, Pa.*
**www.simio.biz**

**New algorithms offered for multicore processors**
This not-for-profit numerical software development organization offers a library of numerical algorithms for chemical research that are optimized for performance on multicore computing architectures. The downloadable NAG Library for Symmetric Multiprocessors (SMP) and Multicore (photo) is designed to help industrial and academic chemical researchers make the best use of the processing power available through the shared-memory parallelism of multicore computer systems. The mathematical and statistical algorithms are key tools in modeling, chemometrics and other chemical engineering research, especially at the nanoscale, the organization says. — *Numerical Algorithms Group, Oxford, U.K.*
**www.nag.com**




Numerical Algorithms Group

**Figure shows the speed increases of using the NAG library for SMP and multicore – NAG routine used "Nearest Correlation Matrix" problem size of N = 10,000**

**New tools included in this flowsheet simulator**
HSC Chemistry 7.0 is process flowsheet simulation software that has four distinct modes — particles, reaction, distribution and experimental. The latest version of the software has added drawing features, new spreadsheet features and routines for mass balancing and data reconciliation. The new distribution mode allows the software's use for high-temperature process models. HSC Chemistry 7.0 contains an enhanced thermodynamic database that includes data on over 25,000 different chemical species. — *Outotec Research Oy, Pori, Finland*
**www.outotec.com/hsc**

**This Web-based design tool can reduce project development costs**
A newly launched front-end design tool from this company allows for rapid development and evaluation of capital project options in the process industries. The software tool integrates flowsheet development, 3-D layout, factored cost estimation and design deliverables generation. Its simple and powerful interface increases engineers' productivity, the company says, asserting that both operating and engineering companies can realize a 50% reduction in project development costs using the software system. Among the features of the software are automatic consistency checks of design parameters across multiple documents, instant updates after design changes, and continuously updated cost estimates based on an industry-accepted price database. — *ConcepSys Solutions LLC, Houston, Tex.*
**www.concepsyssolutions.com**

**Expanded design services offered by this firm**
This company recently introduced an expanded services department to complement its software products. Supporting the petroleum and gas, power, pulp and paper, chemical and aerospace industries, the service department offers plant design and analysis, piping design, data translation, as well as software development and customization, including 2D to 3D drawing conversion. — *SST Systems Inc., San Jose, Calif.*
**www.sstusa.com**

**Use this software package for technical plotting**
PSI-Plot Version 9.5 for Windows is designed for technical plotting and data processing in science and engineering fields. Version 9.5 builds on previous editions, but adds features, including built-in mathematical functions, matrix decomposition and maximum likelihood estimation for generalized linear models. In addition, the software package has added over 100 new predefined fitting models. — *Poly Software International, Pearl River, N.Y.*
**www.polysoftware.com** ■

*Scott Jenkins*

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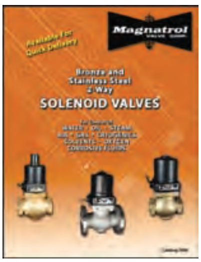


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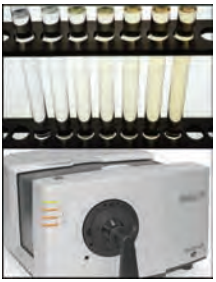

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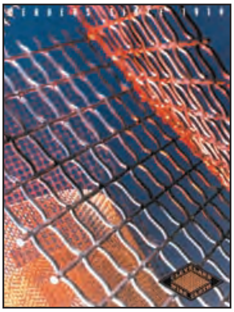

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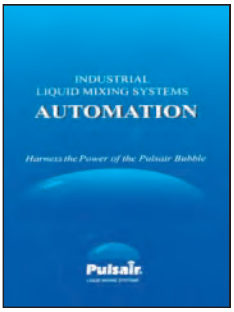
## Mixing Solutions by Pulsair

Equipment




This brochure describes Pulsair's mixing systems that release sequential pulses of air or gas to mix tank contents. Systems are adaptable from a single 55-gallon drum to multiple 1,000,000 gallon tanks and can be managed from a central control unit. Pulsair mixers are currently in use worldwide in the petroleum, lubricant, wastewater, food and wine industries.
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## High Cycle Life Plastic Pinch Valve

***Plast-O-Matic Valves, Inc.*** has developed an all-thermoplastic, air operated pinch valve with a newly designed sleeve element that lasts up to five times longer than traditional designs. The sleeve element in Series HSA is a patent-pending design featuring variable thicknesses and a tapered shape. It is molded from EPDMh2, a new formulation of Ethelyne-Propylene-Diene-Monomer using a proprietary curing process for greater elasticity, durability, and longevity. This elastomer, combined with the new design, enables the pinch element to achieve over 1,000,000 cycles under test conditions. Further Information: *Plast-O-Matic Valves, Inc., 1384 Pompton Ave., Cedar Grove, NJ 07009*

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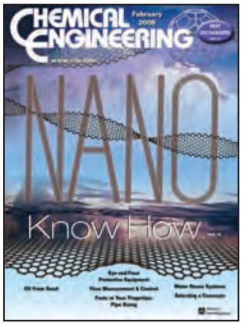


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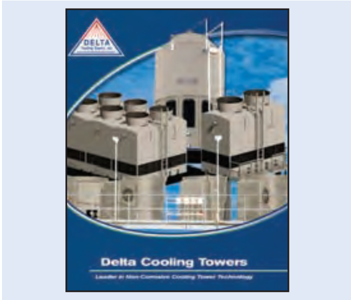
## Delta Cooling Towers, Inc.

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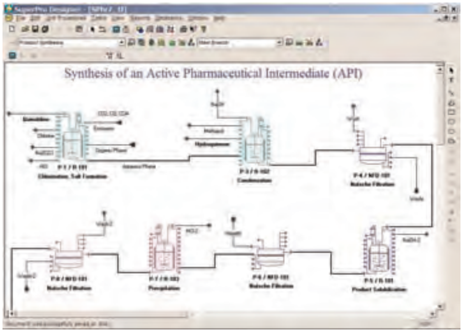
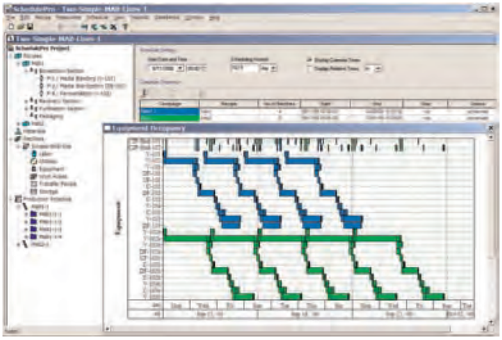
## SuperPro



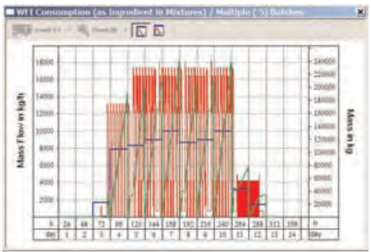

Use SuperPro Designer to model, evaluate, and debottleneck batch and continuous processes


## SchedulePro

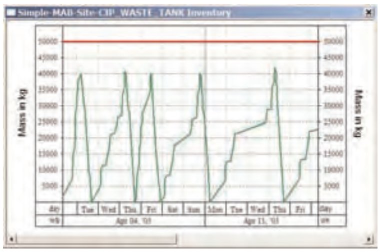


Switch to SchedulePro to schedule, model, and debottleneck multi-product facilities

Tracking of equipment occupancy in multi-product facilities



Tracking demand for resources (e.g., labor, materials, utilities, etc.)



Inventory tracking for raw materials, intermediates, products, and wastes

**SuperPro Designer** is a comprehensive process simulator that facilitates modeling, cost analysis, debottlenecking, cycle time reduction, and environmental impact assessment of biochemical, specialty chemical, pharmaceutical (bulk & fine), food, consumer product, mineral processing, water purification, wastewater treatment, and related processes. Its development was initiated at the Massachusetts Institute of Technology (MIT). SuperPro is already in use at more than 400 companies and 500 universities around the world (including 18 of the top 20 pharmaceutical companies and 9 of the top 10 biopharmaceutical companies).

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CHEMICAL ENGINEERING

**Buyers' Guide 2011**

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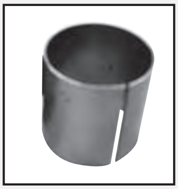

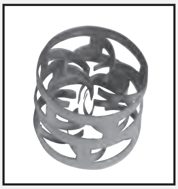

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# Advertisers' Index



* Additional information in 2010 Buyers' Guide

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

## Classified Index - June 2010

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| 2 | 17 | 32 | 47 | 62 | 77 | 92 | 107 | 122 | 137 | 152 | 167 | 182 | 197 | 212 | 227 | 242 | 257 | 272 | 287 | 302 | 317 | 332 | 347 | 362 | 377 | 392 | 407 | 422 | 437 | 452 | 467 | 482 | 497 | 512 | 527 | 542 | 557 | 572 | 587 |
| 3 | 18 | 33 | 48 | 63 | 78 | 93 | 108 | 123 | 138 | 153 | 168 | 183 | 198 | 213 | 228 | 243 | 258 | 273 | 288 | 303 | 318 | 333 | 348 | 363 | 378 | 393 | 408 | 423 | 438 | 453 | 468 | 483 | 498 | 513 | 528 | 543 | 558 | 573 | 588 |
| 4 | 19 | 34 | 49 | 64 | 79 | 94 | 109 | 124 | 139 | 154 | 169 | 184 | 199 | 214 | 229 | 244 | 259 | 274 | 289 | 304 | 319 | 334 | 349 | 364 | 379 | 394 | 409 | 424 | 439 | 454 | 469 | 484 | 499 | 514 | 529 | 544 | 559 | 574 | 589 |
| 5 | 20 | 35 | 50 | 65 | 80 | 95 | 110 | 125 | 140 | 155 | 170 | 185 | 200 | 215 | 230 | 245 | 260 | 275 | 290 | 305 | 320 | 335 | 350 | 365 | 380 | 395 | 410 | 425 | 440 | 455 | 470 | 485 | 500 | 515 | 530 | 545 | 560 | 575 | 590 |
| 6 | 21 | 36 | 51 | 66 | 81 | 96 | 111 | 126 | 141 | 156 | 171 | 186 | 201 | 216 | 231 | 246 | 261 | 276 | 291 | 306 | 321 | 336 | 351 | 366 | 381 | 396 | 411 | 426 | 441 | 456 | 471 | 486 | 501 | 516 | 531 | 546 | 561 | 576 | 591 |
| 7 | 22 | 37 | 52 | 67 | 82 | 97 | 112 | 127 | 142 | 157 | 172 | 187 | 202 | 217 | 232 | 247 | 262 | 277 | 292 | 307 | 322 | 337 | 352 | 367 | 382 | 397 | 412 | 427 | 442 | 457 | 472 | 487 | 502 | 517 | 532 | 547 | 562 | 577 | 592 |
| 8 | 23 | 38 | 53 | 68 | 83 | 98 | 113 | 128 | 143 | 158 | 173 | 188 | 203 | 218 | 233 | 248 | 263 | 278 | 293 | 308 | 323 | 338 | 353 | 368 | 383 | 398 | 413 | 428 | 443 | 458 | 473 | 488 | 503 | 518 | 533 | 548 | 563 | 578 | 593 |
| 9 | 24 | 39 | 54 | 69 | 84 | 99 | 114 | 129 | 144 | 159 | 174 | 189 | 204 | 219 | 234 | 249 | 264 | 279 | 294 | 309 | 324 | 339 | 354 | 369 | 384 | 399 | 414 | 429 | 444 | 459 | 474 | 489 | 504 | 519 | 534 | 549 | 564 | 579 | 594 |
| 10 | 25 | 40 | 55 | 70 | 85 | 100 | 115 | 130 | 145 | 160 | 175 | 190 | 205 | 220 | 235 | 250 | 265 | 280 | 295 | 310 | 325 | 340 | 355 | 370 | 385 | 400 | 415 | 430 | 445 | 460 | 475 | 490 | 505 | 520 | 535 | 550 | 565 | 580 | 595 |
| 11 | 26 | 41 | 56 | 71 | 86 | 101 | 116 | 131 | 146 | 161 | 176 | 191 | 206 | 221 | 236 | 251 | 266 | 281 | 296 | 311 | 326 | 341 | 356 | 371 | 386 | 401 | 416 | 431 | 446 | 461 | 476 | 491 | 506 | 521 | 536 | 551 | 566 | 581 | 596 |
| 12 | 27 | 42 | 57 | 72 | 87 | 102 | 117 | 132 | 147 | 162 | 177 | 192 | 207 | 222 | 237 | 252 | 267 | 282 | 297 | 312 | 327 | 342 | 357 | 372 | 387 | 402 | 417 | 432 | 447 | 462 | 477 | 492 | 507 | 522 | 537 | 552 | 567 | 582 | 597 |
| 13 | 28 | 43 | 58 | 73 | 88 | 103 | 118 | 133 | 148 | 163 | 178 | 193 | 208 | 223 | 238 | 253 | 268 | 283 | 298 | 313 | 328 | 343 | 358 | 373 | 388 | 403 | 418 | 433 | 448 | 463 | 478 | 493 | 508 | 523 | 538 | 553 | 568 | 583 | 598 |
| 14 | 29 | 44 | 59 | 74 | 89 | 104 | 119 | 134 | 149 | 164 | 179 | 194 | 209 | 224 | 239 | 254 | 269 | 284 | 299 | 314 | 329 | 344 | 359 | 374 | 389 | 404 | 419 | 434 | 449 | 464 | 479 | 494 | 509 | 524 | 539 | 554 | 569 | 584 | 599 |
| 15 | 30 | 45 | 60 | 75 | 90 | 105 | 120 | 135 | 150 | 165 | 180 | 195 | 210 | 225 | 240 | 255 | 270 | 285 | 300 | 315 | 330 | 345 | 360 | 375 | 390 | 405 | 420 | 435 | 450 | 465 | 480 | 495 | 510 | 525 | 540 | 555 | 570 | 585 | 600 |

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# BUSINESS NEWS

## PLANT WATCH

**Evonik plans to shut down polyethylene waxes production**

May 21, 2010 — Evonik Industries AG (Essen, Germany; corporate.evonik.com) intends to shut down its production of polyethylene waxes in Heme, Germany at the end of December, 2010. This step was taken as part of a profitability analyses.

**Lonza selects Nansha for new vitamin B3 plant**

May 11, 2010 — Lonza Group Ltd. (Basel, Switzerland; www.lonzagroup.com) has selected Nansha, China as the location for its new vitamin B3 manufacturing site. The new facility will provide an additional 15,000 metric tons per year (m.t./yr) of product, representing an increase of more than 40% over current capacity. Lonza will invest approximately CHF50 million in the construction of the new nicotinate plant over the next three years. The capacity will be added in phases, with the first phase expected to come online in 2011, followed by full operation in 2012.

**Lanxess and TSRC to create rubber JV in China**

May 7, 2010 — Lanxess AG (Leverkusen, Germany; www.lanxess.com) and TSRC Corp. (Taipei, Taiwan; www.tsrc.com.tw) will enter into a 50:50 joint venture (JV) in Greater China called Lanxess-TSRC (Nantong) Chemical Industrial Company Ltd. The two companies are jointly investing $50 million in a new plant that will produce nitrile rubber (NBR) in Nantong. The plant will have an initial capacity of 30,000 m.t./yr. Groundbreaking is scheduled for September, 2010, and production is expected to start in the first half of 2012. Clearance for the JV from the relevant anti-trust authorities is expected by the end of July, 2010.

**DuPont Tate & Lyle Bio Products expanding Bio-PDO production**

May 5, 2010 — DuPont Tate & Lyle Bio Products, LLC (Loudon, Tenn), a JV between DuPont (www.dupont.com) and Tate & Lyle (www.tateandlyle.com), have announced an expansion to their facility to increase production of bio-based 1,3 propanediol (Bio-PDO) by 35%. Construction is scheduled to start in June, and the expansion is expected to be complete by 2nd Q 2011.

**Linde builds air separation unit in Kazakhstan**

May 5, 2010 — The Linde Group (Munich, Germany; www.linde.com) is set to construct a large, state-of-the-art air separation unit (ASU) for ArcelorMittal, the world's largest steel corporation, at ArcelorMittal's Temirtau site in Kazakhstan. This plant will be Kazakhstan's first industrial-scale development with a capacity of 2,000 m.t./d and has an investment value of around €95 million. It is set to go onstream mid-2012.

**SNF invests to increase global manufacturing by 50%**

April 21, 2010 — SNF (Andrézieux, France; www.snf-group.com) is investing in new production capacities starting in 2010 through 2012. Total production will increase from 380,000 ton/yr to 580,000 ton/yr as follows: In Plaquemine, La. a 50,000-ton/yr acrylamide plant and four 20,000-ton/yr anionic powder plants; In Taixing, China, a 50,000-ton/yr acrylamide plant and four 20,000-ton/yr anionic powder plants and the opening of two 20,000-ton/yr cationic powder plants; In Andrézieux, France, 20,000 ton/yr of anionic polymer and 10,000 ton/yr of cationic polymer; A new plant in Vizag, India to produce polyacrylamide emulsions and liquid followed by acrylamide and powder polyacrylamide.

**HPD to supply systems for sodium sulfate production**

April 20, 2010 — Alkim Alkali Kimya A.S. (Alkim, Instanbul, Turkey; www.alkim.com/tr/index.aspx) has selected HPD (Plainfield, Ill.; www.hpdsystems.com), a Veolia Water Solutions & Technologies company, to supply evaporation and crystallization process equipment for their new greenfield plant in Çayırhan, Turkey. The new plant will produce 120,000 ton/yr of pure sodium sulfate from glauberite, extracted through a unique solution mining process. The HPD system produces glauber salt as a first purification step followed by re-crystallization to an anhydrous sodium sulfate in a multi-effect evaporator. The end product is a key component in consumer products, pulp & paper, and the textile industry.

## MERGERS AND ACQUISITIONS

**Honeywell and DuPont announce JV for new refrigerant**

May 20, 2010 — Honeywell (Morristown, N.J.; www.honeywell.com) and DuPont (Wilmington, Del.; www.dupont.com) have announced a manufacturing JV to produce a new refrigerant for use in automotive air-conditioning systems. The new refrigerant is said to have 99.7% lower global warming potential than the current refrigerant. Under the agreement, DuPont and Honeywell will share financial and technological resources with the intent to jointly design, construct and operate a manufacturing facility for the new product. Prior to the construction of the new plant, the JV will begin supplying the new refrigerant in the 4th Q 2011, in time to meet EU regulatory requirements.

**Omnova Solutions completes acquisition of Dow Chemical's product line**

May 17, 2010 — Omnova Solutions Inc. (Fairlawn, Ohio; www.omnova.com) has completed the acquisition of The Dow Chemical Co.'s (Midland, Mich.; www.dow.com) hollow sphere plastic pigment (HPP) product line. Concurrently, the RohmNova paper coatings JV has been terminated. The termination was necessitated by Dow Chemical's acquisition of the JV partner, Rohm and Haas Co.

**Evonik Industries, Tasnee and Sahara plan JV to produce superabsorbents**

April 26, 2010 — Evonik Industries AG (Essen, Germany; corporate.evonik.com), National Industrialization Co. and Sahara Petrochemicals are planning to set up a JV to produce superabsorbent polymers. Their intention is to build a state-of-the-art facility with a 80,000-m.t./yr capacity at Jubail in Saudi-Arabia. Startup would be in the 1st Q of 2013.

**Songwon and Tangszhan Baifu to form a JV**

April 19, 2010 — Songwon Industrial Co. (Ulsan, Korea; www.songwonind.com) and Tangshan Baifu Chemical Ltd. have announced their intention to form a JV to manufacture and sell thioester antioxidants. The two companies have signed a memorandum of understanding whereby Songwon will take an initial stake of 30% in Tangshan Baifu Chemical Ltd. with the option to extend its share to up to 50% at a later date. The JV will be operational by January 1, 2011. ■

*Dorothy Lozowski*

For consideration in this section, please send press releases to biznews@che.com

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FOR MORE ECONOMIC INDICATORS, SEE NEXT PAGE

# Economic Indicators

2010 | 2009 | 2008

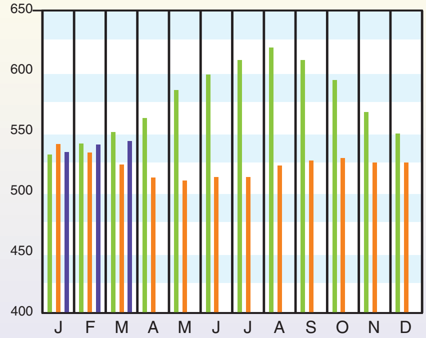
**DOWNLOAD THE *CEPCI* TWO WEEKS SOONER AT *WWW.CHE.COM/PCI***

## CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

| (1957-59 = 100) | Mar.'10 Prelim. | Feb.'10 Final | Mar.'09 Final |
|---|---|---|---|
| ***CE* Index** | 541.8 | 539.1 | 522.6 |
| Equipment | 645.5 | 641.1 | 616.6 |
| Heat exchangers & tanks | 592.5 | 587.3 | 563.2 |
| Process machinery | 614.1 | 610.3 | 597.3 |
| Pipe, valves & fittings | 801.7 | 796.1 | 761.0 |
| Process instruments | 421.0 | 420.5 | 385.1 |
| Pumps & compressors | 903.4 | 903.4 | 898.0 |
| Electrical equipment | 472.1 | 468.4 | 459.6 |
| Structural supports & misc | 665.6 | 660.0 | 636.1 |
| Construction labor | 328.4 | 330.2 | 325.7 |
| Buildings | 504.3 | 500.5 | 494.9 |
| Engineering & supervision | 341.8 | 342.4 | 349.0 |

**Annual Index:**
- 2002 = 395.6
- 2003 = 402.0
- 2004 = 444.2
- 2005 = 468.2
- 2006 = 499.6
- 2007 = 525.4
- 2008 = 575.4
- 2009 = 521.9

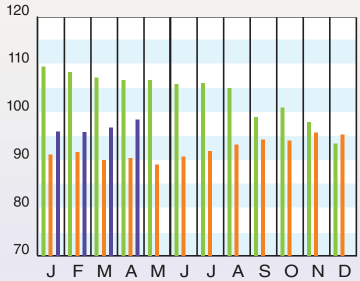
Starting with the April 2007 Final numbers, several of the data series for labor and compressors have been converted to accommodate series IDs that were discontinued by the U.S. Bureau of Labor Statistics



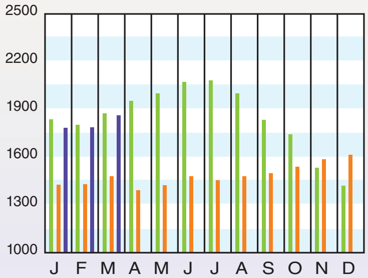

## CURRENT BUSINESS INDICATORS

| | LATEST | | PREVIOUS | | | | YEAR AGO | |
|---|---|---|---|---|---|---|---|---|
| CPI output index (2000 = 100) | Apr.'10 | = 98.5 | Mar.'10 | = 96.8 | Feb.'10 | = 95.9 | Apr.'09 | = 90.4 |
| CPI value of output, $ billions | Mar.'10 | = 1,864.7 | Feb.'10 | = 1,789.6 | Jan.'10 | = 1,786.8 | Mar.'09 | = 1,482.0 |
| CPI operating rate, % | Apr.'10 | = 73.5 | Mar.'10 | = 72.1 | Feb.'10 | = 71.3 | Apr.'09 | = 65.9 |
| Producer prices, industrial chemicals (1982 = 100) | Apr.'10 | = 274.0 | Mar.'10 | = 273.3 | Feb.'10 | = 265.7 | Apr.'09 | = 220.1 |
| Industrial Production in Manufacturing (2002=100)* | Apr.'10 | = 101.4 | Mar.'10 | = 100.4 | Feb.'10 | = 99.4 | Apr.'09 | = 95.7 |
| Hourly earnings index, chemical & allied products (1992 = 100) | Apr.'10 | = 151.5 | Mar.'10 | = 150.0 | Feb.'10 | = 150.4 | Apr.'09 | = 146.4 |
| Productivity index, chemicals & allied products (1992 = 100) | Apr.'10 | = 138.6 | Mar.'10 | = 137.2 | Feb.'10 | = 138.0 | Apr.'09 | = 133.1 |

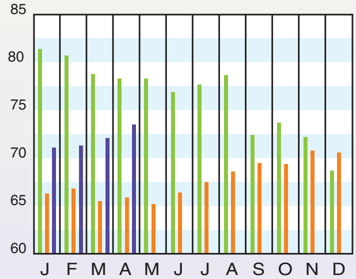
### CPI OUTPUT INDEX (2000 = 100)




### CPI OUTPUT VALUE ($ BILLIONS)




### CPI OPERATING RATE (%)

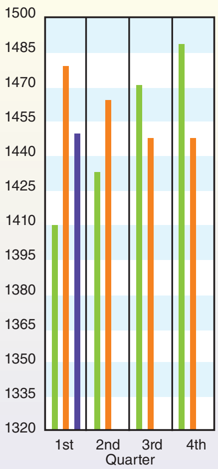



## MARSHALL & SWIFT EQUIPMENT COST INDEX

| (1926 = 100) | 1st Q 2010 | 4th Q 2009 | 3rd Q 2009 | 2nd Q 2009 | 1st Q 2009 |
|---|---|---|---|---|---|
| **M & S INDEX** | 1,448.3 | 1,446.5 | 1,446.4 | 1,462.9 | 1,477.7 |
| **Process industries, average** | 1,510.3 | 1,511.9 | 1,515.1 | 1,534.2 | 1,553.2 |
| **Cement** | 1,508.1 | 1,508.2 | 1,509.7 | 1,532.5 | 1,551.1 |
| **Chemicals** | 1,481.8 | 1,483.1 | 1,485.8 | 1,504.8 | 1,523.8 |
| **Clay products** | 1,496.0 | 1,494.3 | 1,495.8 | 1,512.9 | 1,526.4 |
| **Glass** | 1,403.0 | 1,400.1 | 1,400.4 | 1,420.1 | 1,439.8 |
| **Paint** | 1,515.1 | 1,514.1 | 1,515.1 | 1,535.9 | 1,554.1 |
| **Paper** | 1,416.4 | 1,415.8 | 1,416.3 | 1,435.6 | 1,453.3 |
| **Petroleum products** | 1,615.6 | 1,617.6 | 1,625.2 | 1,643.5 | 1,663.6 |
| **Rubber** | 1,551.0 | 1,560.5 | 1,560.7 | 1,581.1 | 1,600.3 |
| **Related industries** | | | | | |
| **Electrical power** | 1,389.6 | 1,377.3 | 1,370.8 | 1,394.7 | 1,425.0 |
| **Mining, milling** | 1,552.1 | 1,548.1 | 1,547.6 | 1,562.9 | 1,573.0 |
| **Refrigeration** | 1,772.2 | 1,769.5 | 1,767.3 | 1,789.0 | 1,807.3 |
| **Steam power** | 1,475.0 | 1,470.8 | 1,471.4 | 1,490.8 | 1,509.3 |

**Annual Index:**

| | | | |
|---|---|---|---|
| 2002 = 1,104.2 | 2004 = 1,178.5 | 2006 = 1,302.3 | 2008 = 1,449.3 |
| 2003 = 1,123.6 | 2005 = 1,244.5 | 2007 = 1,373.3 | 2009 = 1,468.6 |






## CURRENT TRENDS

Typically, the graphs on this page display data for two years: the current and previous years, which would in this case correspond to 2010 and 2009. In last month's issue, however, we began including data for one additional year, 2008, because true economic recovery not only requires that we surpass 2009 levels, but that we also exceed those of early 2008.

In the Feburary CEPCI the 2009 milestone was surpassed. And although the gap between 2010 and 2008 continues to narrow with the March preliminary CEPCI, it has not yet been erased.

Visit www.che.com/pci for more on capital cost trends and methodology. ■