CHEMICAL ENGINEERING

February 2011

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Coal-to-Chemicals

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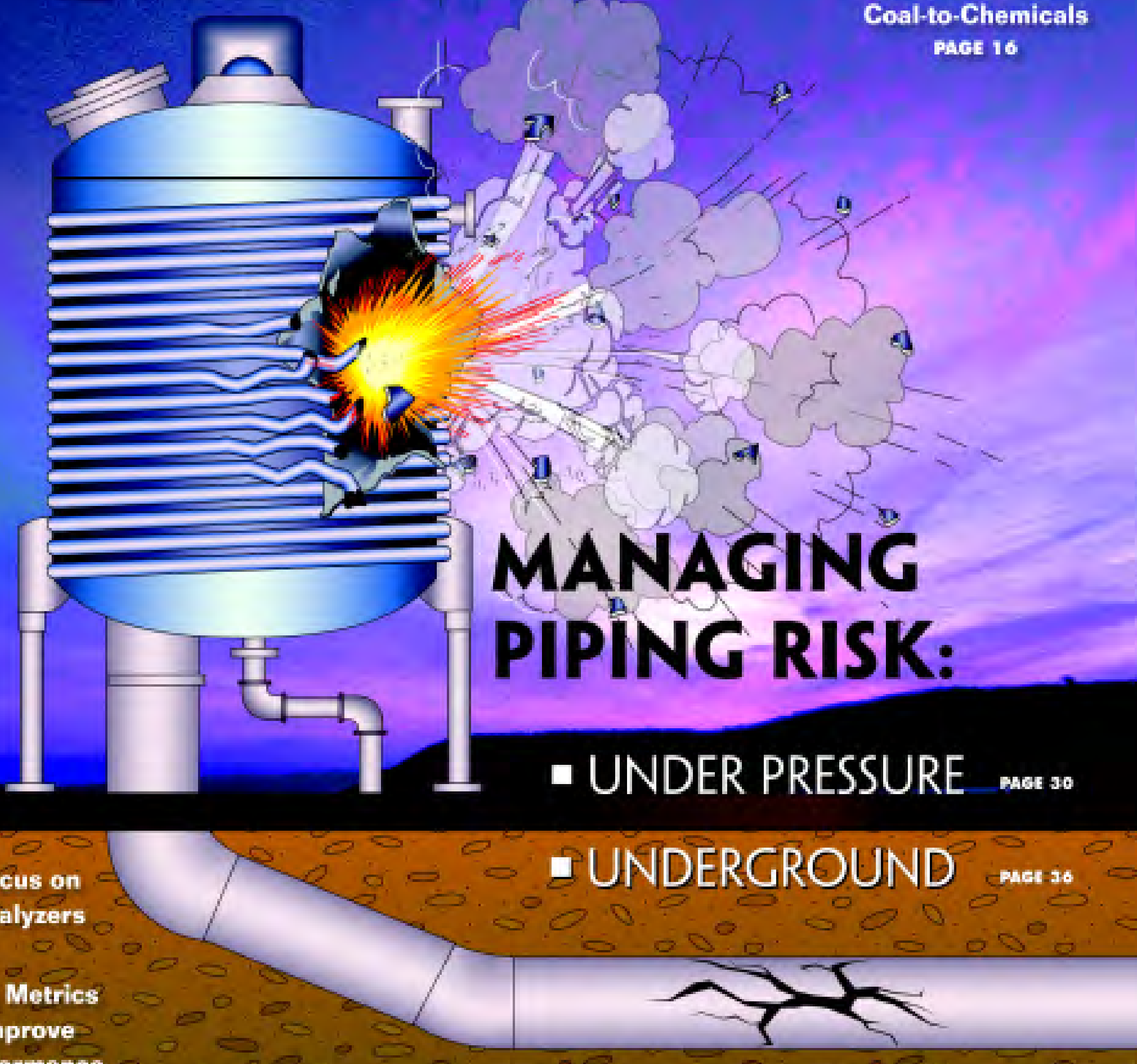

MANAGING PIPING RISK:

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Cover: David Whitcher

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CHEMICAL ENGINEERING

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Editor's Page

Put coal back on the map

When I was growing up in western Pennsylvania, we used to have notebooks in school with a map of the state on the cover. Back then (1960s), local children quickly learned that by tracing the boundaries of certain counties, one could create a silhouette of a coal miner at the center of the state. The point is, coal was important; we heated our homes with it, we burned it to make electricity, and if we misbehaved, Santa Claus filled our stocking with it.

Of course, back then the coal industry was beginning to come under fire, not only for the environmental damage caused by coal mining (especially strip mines), but also because of damage to the forests caused by acid rain, which was correlated to the SO_2 emissions from coal-fired power plants.

Today, coal-fired power plants are running much cleaner than four decades ago thanks to environmental controls for SO_2, NOx, Hg and dust — controls that were added to comply with ever tightening regulations. And now, the U.S. Environmental Protection Agency (EPA; Washington, D.C.) is moving to regulate coal-fired plants even more, not only with respect to the greenhouse gas (GHG) carbon dioxide, but also with respect to cooling water and the disposal of coal-combustion residuals.

This is not the place, nor is there space available to discuss the pros and cons of stricter EPA regulations on the power and petroleum refining industries — the two sectors EPA claims are the biggest industrial sources for GHG emissions in the U.S. — not to mention the timing of doing so following one of the most difficult economic times in U.S. history. The issues involved are very complex, both scientifically and economically.

The fact is, however, that the last two to three years have seen a large number of coal-related projects in the U.S. either cancelled, put on hold or changed mid course. In the power sector, it's very difficult to receive permitting to build conventional coal-fired plants. Advanced power generation projects, such as integrated gasification combined cycle (IGCC), have been cancelled, too. Although there are many reasons for these cancellations — rising construction costs and the growing availability of cheap unconventional natural gas, to name just two — uncertainties about pending and future regulations regarding GHGs is the one reason most cited for halting coal-based projects. Investors are not willing to put the money forward for a 5–6 year project when the playing field might change two years into the project.

China, in contrast, seems to be a country with long-term goals to utilize its abundant coal reserves — for making electricity, for making liquid fuels and substitute natural gas, and for making basic chemicals (see "Coal-to-Chemicals", pp. 16–20). Although many of these mega projects do not include carbon capture, many *are* using advanced technology for the first time, or integrating production units that can utilize byproducts (for example, urea production is CO_2 negative).

Last November, U.S. Energy Secretary Chu said that the success of China and other countries in clean energy industries represents a new "Sputnik Moment" for the U.S. and requires a similar mobilization of America's innovative machine. Let's hope that Secretary Chu's call does not fall on deaf ears, and the country moves forward to better utilize its large coal reserves in an environmentally sound fashion.

Although the costs may seem insurmountable today — just as they did 30–40 years ago with regards to adding scrubbers to remove SO_2 and other pollutants from the fluegas of coal-fired power plants — we should be encouraged by the efforts underway to make coal plants more efficient and cleaner. Chemical engineers are driving these efforts; let's hope they will receive the support necessary to carry them through. ■

Gerald Ondrey, Senior Editor, Frankfurt

Letters

How efficiency is calculated

September 2010, Recover Waste Heat From Fluegas, pp. 37–40: I have performed a basic energy balance for the examples in the article and am baffled that their Orangic Rankine Cycle (ORC) efficiency is over 100%.

Dannis Jen
Houston

Author replies

The focus of the article is on demonstrating a means of cooling fluegas that produces net electrical energy output. The reader's assumption that efficiency is equal to actual work divided by heat input is correct. However, his calculation is incorrect. In attempting a heat balance to determine the fluegas exchanger duty, the reader has used electrical consumptions of the pump and condenser motors, evidently mistaking those values for thermal duties. The actual work, simply, is equal to the net power produced (calculated by subtracting the power consumed by the pump and the condenser motors from the power produced by the generator attached to the turbine). In other words, the tables in the article reflect electrical energy to and from the system, not thermal energy. The heat input cannot actually be calculated from the information given in the article; the specific heat of the fluegas is needed. Assuming that the composition of the fluegas stream is 100% CO_2, the specific heat value can be calculated, from which a heat balance can be performed.

It is a good question. The article did not address the efficiency of the ORC cycle. This dialogue will shed more light on the ORC application and add value to all interested parties. An energy conversion efficiency calculation has been added to the online version of the article at www.che.com.

Ali Bourji
WorleyParsons, Bellaire, Tex.

Steam thermodynamics

Brad Buecker's article, Steam Generation Thermodynamics (November 2010, pp. 44–47), was excellent — good information without getting bogged down with too much theory and formulae. I never had formal education in thermodynamics so some of the examples he stated were over my head. Still his explanations enabled me to refresh my knowledge at a level that I could understand. I spent my career sailing in ship's engine rooms for the U.S. Coast Guard and Chevron Shipping Co. Along the way I also was a boiler operator at a small power plant (1,060,000 lb/h). I have had much experience working on boilers from tube repair and water chemistry to soot blower maintenance and air casing repair. Although all the systems were in place and working well at my plants, I enjoyed reading about the theory surrounding steam generation and why the designers put in a certain piece of equipment. Marine steam-power plants obviously are in a limited space, which makes it easier to trace out steam, water and fuel systems. On one ship I could light off the whole steam plant by myself. I will save the magazine in my file and continue to review it. Thank you.

Brian T. Bender
Napa, Calif.

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NORTH AMERICA

TMS 2011 Annual Meeting & Exhibition. Minerals, Metals & Materials Soc. (Warrendale, Pa.). Phone: 724-776-9000, ext. 243; Web: tms.org
San Diego, Calif. **February 27–March 3**

Personal Care Products Council Annual Meeting. Personal Care Products Council (Washington, D.C.). Phone: 202-331-1770; Web: personalcarecouncil.org
Palm Beach, Fla. **February 28–March 2**

NPRA 2011 Security Conference. National Petrochemical & Refiners Assn. (NPRA; Washington, D.C.). Phone: 202-457-0480; Web: npra.org
Houston, Tex. **March 1–2**

Biophysical Society, 55th Annual Meeting. Biophysical Society (Bethesda, Md.). Phone: 301-634-7114; Web: biophysics.org
Baltimore, Md. **March 5–9**

Inorganic Reaction Mechanisms. Gordon Research Conferences (West Kingston, R.I.). Fax: 401-783-7644; Web: grc.org
Galveston, Tex. **March 6–11**

21st International Conference: Molding 2011. Executive Conference Management (Plymouth, Mich.). Phone: 734-737-0507; Web: executive-conference.com
San Diego, Calif. **March 7–9**

AIChE Spring National Meeting. American Institute of Chemical Engineers (New York). Phone: 646-495-1360; Web: aiche.org/SBE/Events/Spring.aspx
Chicago **March 13–17**

Pittcon 2011. Pittsburgh Conference on Analytical Chemistry & Applied Spectroscopy (Pittsburgh, Pa.). Phone: 412-825-3220; Web: pittcon.org
Atlanta, Ga. **March 13–18**

DCAT Week 2011. Drug, Chemical & Associated Technologies Assn. (Robbinsville, N.J.). Phone: 609-448-1000; Web: dcat.org
New York, N.Y. **March 14–17**

NPRA Annual Meeting. National Petrochemical Refiners Assn. (Washington, D.C.). Phone: 202-457-0486; Web: npra.org
San Antonio, Tex. **March 20–22**

(Continues)

Calendar

2011 International Petrochemical Conference. NPRA (Washington, D.C.). Phone: 202-457-0486; Web: npra.org
San Antonio, Tex. **March 27–29**

ACS 227th National Meeting & Expo. American Chemical Soc. (Washington, D.C.). Phone: 800-227-5558; Web: portal.acs.org
Anaheim, Calif. **March 27–31**

Interphex 2011. Reed Exhibitions (Norwalk, Conn.). Phone: 203-840-4800; Email: inquiry@interphex.com; Web: interphex.com
New York, N.Y. **March 29–31**

EUROPE

European Chemical Manufacturing Masters 2011. Econique Business Masters GmbH (Berlin). Phone: +49-30-8020-8040; Web: business-masters.econique.com
Berlin, Germany **Feb 28–March 1**

Hybrid Materials 2011 — 2nd International Conference on Multifunctional, Hybrid & Nanomaterials. Elsevier (Oxford, U.K.). Phone: +44-86-10-8520-8856; Web: hybridmaterialsconference.com
Strasbourg, France **March 6–10**

European Coatings Show 2011. Nürnberg Messe GmbH (Nürnberg, Germany). Phone: +49-911-86-06-0; Web: european-coatings-show.com
Nürnberg, Germany **March 29–31**

LogiChem 2011. World Business Research (London). Phone: +44-20-7368-9465; Web: logichemeurope.com
Antwerp, Belgium **April 5–7**

ASIA & ELSEWHERE

Semicon China 2011. SEMI China (Shanghai). Phone: +86-21-5027-0909 Web: semiconchina.semi.org
Shanghai, China **March 15–17**

ChemSpec India. ChemSpec India (Mumbai). Phone: +91-222-40-44477; Web: chemspecindia.com
Mumbai **April 14–15**

CPhI Japan. UBM Japan Co. Ltd. (Tokyo). Phone: +81-3-5296-1020; Web: cphijapan.com
Tokyo **April 18–20** ■

Suzanne Shelley

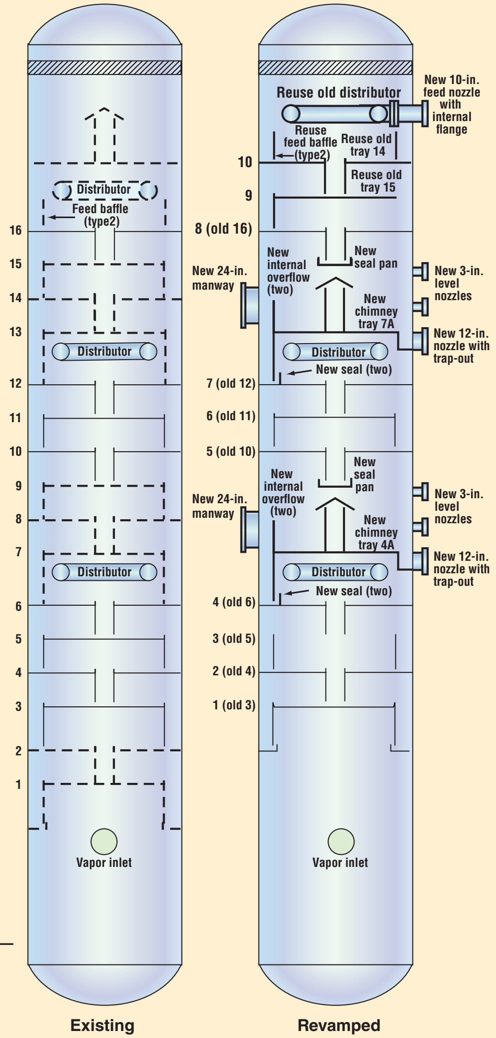
‘Cool’ amine process improves H_2S absorption

A novel process for removing hydrogen sulfide from natural gas has been started up at Sinopec Zhongyuan Petroleum Co.’s Puguang natural gas plant in China’s Sichuan Province. The plant, Asia’s largest sour natural-gas treatment facility, can process up to 36 million Nm^3/d of gas, while the H_2S recovery unit will yield up to 3 million metric tons per year (m.t./yr) of elemental sulfur, enough to meet more than 25% of China’s needs.

The H_2S plant marks the first large-scale application of technology offered by Black & Veatch (B&V; Overland Park, Kan.; www.bv.com). Co-developed and patented by B&V and Shell Global Solutions (www.shell.com; Houston), the process has been installed in one other plant, a former Motiva refinery. The process is conventional in that it uses monodiethanolamine (MDEA) to extract H_2S and carbon dioxide from the gas in an absorption column. Elemental sulfur is recovered by the Claus process.

However, B&V’s interstage cooling technology differs in that semi-lean solvent is removed from an intermediate stage in the absorption column, pumped through a water-cooled heat exchanger, and returned to the column (diagram). “H_2S absorption is favored at lower temperatures, and CO_2 is favored at higher temperatures, so cooling the solvent at an intermediate stage in the column enables better H_2S-to-CO_2 selectivity and lower circulation rates,” notes Angela Slavens, B&V’s vice president and manager of sulfur technologies.

The process is designed to slip enough CO_2 to meet pipeline specifications, which maximizes gas volume for sale. “The key to achieving the desired H_2S and CO_2 removal rates is to regulate the interstage, semi-lean solvent temperature, which is the foundation of the interstage cooling technology,” she says. The Puguang plant reduces the H_2S content of the raw gas from nearly 15 vol% to virtually zero, and the CO_2 content from 10 vol% to 3 vol%. Slavens says the improved efficiency of the interstage cooling system over conventional technology allows “significant savings” in capital and operating costs.



No oxygen is needed for this gasifier

A pilot plant for a process that uses a fluidized bed of sand to gasify coal and other carbonaceous materials will be started up this summer in Kanab, Utah by Viresco Energy LLC (Riverside, Calif.; www.virescoenergy.com). Initially, the plant will convert 5 ton/d of low-rank coal into synthesis gas (syngas), says Jim Guthrie, Viresco president. Later, the company plans to add biomass and biosolids from wastewater treatment plants, which will be mixed with the coal or used alone (for more on coal-to-chemicals, see pp. 16–19).

Unlike conventional partial oxidation processes, Viresco’s gasifier doesn’t use oxygen, thereby avoiding the cost of an air-separation plant, says director of research Arun Raju. Air is used only in the regenerator to heat the sand. Another benefit, he says, is that it uses wet feed, whereas conventional gasifiers are designed for dry feed and employ a lot of energy to demoisturize wet feed.

In Viresco’s steam hydrogasification and reforming (SHR) process, a slurry of coal or mixed feed is reacted with steam and hydrogen (from the process) at “under 1,000°C” and “less than 1,000 psi” to produce a methane-rich gas. The gas can be converted to substitute natural gas or reformed to generate syngas. Viresco has done small-scale tests with a variety of feeds, including biosolids from wastewater treatment plants that contain up to 95% water says Raju. The biosolids are mixed with feeds that have a higher energy content, such as coal or biomass, to obtain a desired feed-to-water ratio.

Guthrie says a commercial plant could yield “a considerably higher rate of return” than conventional plants. He adds that the process could be profitable for small plants of 300–400 ton/d.

DuPont acquisition

Last month, DuPont (Wilmington, Del.; www.dupont.com) announced its plans to acquire Danisco, a global enzyme and specialty food ingredients company, for $5.8 billion in cash and assumption of $500 million of Danisco’s net debt. Danisco is a technology-driven organization, with strong research and application development capabilities. The company’s specialty food ingredients generate about 65% of total sales; and Genencor, its enzymes division, represents 35% of total sales. The transaction is expected to close early in the second quarter.

Note: For more information, circle the 3-digit number on p. 54, or use the website designation.

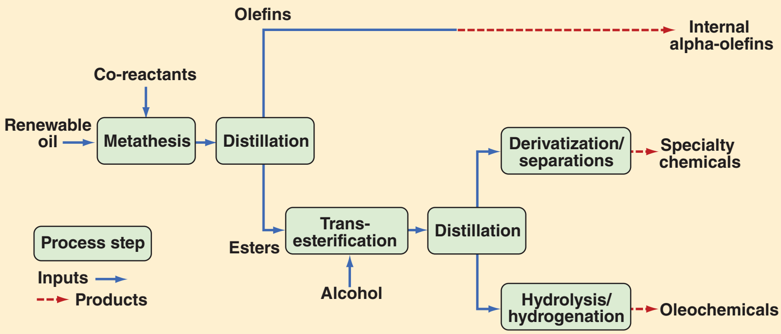
Elevance biorefinery on track for late-2011 commissioning

A manufacturing facility for bio-based intermediate and specialty chemicals under construction by Elevance Renewable Sciences Inc. (Bolingbrook, Ill.; www.elevance.com) is on track to begin generating products late this year, according to the company.

Located in Indonesia, the facility is currently undergoing site preparation work, says Elevance executive vice president of sales and market development Andy Shafer, and the company is now procuring long lead-time items needed for construction. Once complete, the capacity at the facility will reach 180,000 m.t./yr.

The plant's initial products will be internal- and alpha-olefins of more than six carbons, as well as 9-decenoic esters and 18-carbon diesters, Shafer says. All Elevance products are derived from plant oils and synthesized using olefin metathesis chemistry — reactions in which chemical groups attached to a double bond change locations in the presence of a specialized catalyst.

Key process steps in the biorefinery will include the metathesis reaction, followed by a distillation step to separate the resulting olefins, and a trans-esterification step to generate the desired ester (flowsheet).



A final distillation step separates different ester products.

"Although we have successfully carried out full-scale metathesis reactions in batch production, the biorefinery will mark the first time we will operate a continuous process that couples the metathesis with the separation steps in the same location," explains Shafer.

Representing a joint venture between Elevance and Wilmar International Ltd. (Singapore; www.wilmar-international.com), the Indonesia facility is built at an existing Wilmar property. The location will allow the biorefinery to take advantage of existing product transport and feedstock storage infrastructure. The Elevance biorefinery is being built on a geographical footprint that allows for eventual expansion to double the capacity to 360,000 m.t./yr, Shafer says.

A streamlined pre-treatment process for algae biodiesel

A pulsed-electric-field (PEF) pre-treatment technology to facilitate extraction of oils from algae cells was introduced recently by Diversified Technologies Inc. (Bedford, Mass.; www.divtecs.com). Algae have drawn considerable interest as a renewable source of biofuels, but the costs of algae-derived fuels remain much higher than petroleum-derived fuels.

The scalable PEF method could significantly lower the cost of extracting biodiesel from algae cells. "We calculate that the PEF treatment would account for approximately $0.10/gal of the price of algae-derived fuel," says Michael Kempkes, vice president of marketing. The price is significantly lower than the $1.75/gal that is required for the conventional drying and solvent extraction process, he says.

The PEF technology exploits a cellular property called electroporation, a well-studied effect used previously in the genetic engineering field, whereby pores in the outer cell membrane open in response to an electric field. "If you apply a high-enough voltage for a long-enough time, the pores open so far that the cell membrane ruptures," explains Kempkes. The PEF method liberates the oils contained in the vacuoles of the algae cells, and also allows improved access to oils in the cell wall.

As the algal slurry flows through a treatment chamber, electric pulses of between 10 and 30 kV/cm in intensity and typically between 2 and 20 µs in duration are applied from a pulse modulator. The PEF process has been used successfully in the food industry to disinfect juice, as well as in wastewater treatment.

Diversified Technologies was recently awarded a Small Business Innovation Research grant from the National Science Foundation (Arlington, Va.; www.nsf.gov) to develop the technique for different types of algae. Another technology for extracting oil from algae is under development by OriginOil Inc. (Los Angeles, Calif.; www.originoil.com) (*CE,* June 1, 2009, p. 12).

Nanotube rubber

A new form of rubber, made from long, tangled strands of single-, double- and triple-walled carbon nanotubes (CNTs) has been formulated by a team from the Nanotube Research Center at Japan's National Institute of Advanced Industrial Science & Technology (www.aist.go.jp). The material retains its viscoelasticity at a much wider temperature range (–196 – 1,000°C) than conventional rubbers.

Combining reactive ion etching to the catalyst film used to grow the CNTs, along with water-assisted chemical vapor deposition and compression, the team assembled long CNTs with a high density of intermittent physical interconnections. The team found an inter-tube structure where individual CNTs traversed laterally, interconnecting nearby CNTs. This allows the material to bear strain without fracture. The porous nature of the material allows for rapid heat dissipation, which prevents degradation.

New yeast strain

A large research collective, led by University of Illinois (Champaign; www.illinois.edu) professor Yong-Su Jin, has developed a new yeast strain that is capable of consuming xylose in addition to glucose as a substrate for producing ethanol. Xylose, a five-carbon sugar found abundantly in lignocellulosic biomass, is not normally metabolized by most yeasts, including the bioethanol-producing *Saccharomyces cerevisiae*.

By combining and optimizing earlier genetic engineering advances, the researchers have

(*Continues on p. 14*)

Nippon Ketjen introduces new catalysts for residue hydrotreating

Nippon Ketjen Co. (Tokyo; www.nippon-ketjen.co.jp) has developed two new catalysts with enhanced properties for petroleum residue hydrotreating. KFR 15 removes metallic impurities, and KFR 93 removes sulfur from residues and contributes to the efficiency of residue hydrotreating units.

For the metal-removal catalyst, Nippon Ketjen adopted new support technology, enhanced pore volumes and optimized pore structures and surface area. The enhancements increased diffusion of metal-containing compounds into catalyst pores by 20%, and maximum retentive capacity of the metal was raised by 10%. KFR 15 showed higher catalytic performance compared to the existing catalyst system at startup of the operation, and also showed improved performance at higher temperatures, after the midpoint of continuous operation.

The company also optimized the pore structures for its new desulfurization catalyst, while using a common industrial support material, and optimized the active metallic species and its support amount. These enhancements enabled high desulfurization performance at temperatures 10°C higher than existing catalysts.

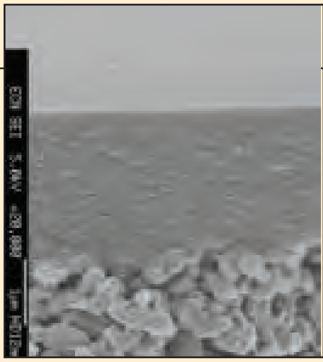
In addition to improvements to the catalysts themselves, Nippon Ketjen also developed a combined catalyst system, using KFR 15 instead of the existing metallization catalyst, and replacing half of the existing desulfurization catalyst with KFR 93. Using this system, the company confirmed that it could operate a residue-treating unit at lower temperatures than the existing system, and prolong catalyst life by one month. Nippon Ketjen calculates that the combined catalyst system could reduce catalyst usage at an FCC (fluid catalytic cracking) unit by 20–30%, due to the lowered metal content.

Nanoparticle alloy could be an alternative to palladium

Kyoto University (Kyoto, www.kuchem.kyoto-u.ac.jp) professor Hiroshi Kitagawa has developed technology for synthesizing nanoscale particles of alloyed metals that could lead to alternatives to industrially important, but expensive, metals such as Pd and rare earth metals. Kitagawa's group has used the technology in the first synthesis of atomic-level rhodium/silver-alloy nanoparticles using a chemical reduction procedure. The 10 nm-dia. particles mimic properties of Pd metal.

Kitagawa focused on rhodium and silver, which have one fewer, and one more outer-shell electron, respectively, than Pd. To make the 1:1 Ag-Rh nanoparticles, $AgNO_3$ and $Rh(CH_3COO)_3$ were dissolved in water in a 50:50 molar

(Continues on p. 14)



Hybrid inorganic-organic membrane has enhanced stability

A silica-based amorphous material in which silicon atoms are linked to organic groups, as well as to oxygen, creates a pore network that tolerates aggressive chemical environments more effectively than conventional polymeric or ceramic membranes.

Licensed by membrane manufacturer Pervatech BV (Enter, the Netherlands; www.pervatech.com) from the Energy research Centre of the Netherlands (ECN; Petten, the Netherlands; www.ecn.nl), the HybSi membrane exhibits increased stability and longer lifetimes in acidic environments, with aggressive organic solvents and at higher temperatures compared to polymeric and ceramic membranes. The enhanced stability is thought to derive in large part from the replacement of Si-O-Si bonds with Si-(organic)-Si bonds. The organic groups act as integral bridging fragments of the membrane structure.

HybSi membranes can be used in two modes — pervaporation or vapor permeation. Driven by a vapor-pressure gradient across membranes, pervaporation can be enhanced by applying low pressure on the permeate side and high temperatures on the feed side. The HybSi technology maintains stability and long life in this environment.

Pervatech CEO Frans Velterop says the company calculated that replacing an azeotropic distillation system with a pervaporation process could allow up to 80% in energy savings.

The membrane is prepared using a proprietary sol-gel process in which a carefully prepared solution containing bis-silyl precursors is deposited onto a ceramic substrate. The coating process is followed by drying and sintering steps. Precise execution of the process yields a membrane (photo) that is effective for separating azeotropic mixtures, dewatering industrial solvents and separating low-molecular-weight compounds (such as CH_3OH and NH_3) from higher-molecular-weight solvents. In addition, the HybSi membrane can be used for in situ dehydration of condensation reaction mixtures.

Recovering rare earth metals from used light bulbs

Up to now, used energy-saving light bulbs have been processed by recycling firms that recover the various components, such as glass, metal, plastics and mercury. However, the remaining luminescent powders, which contain high concentrations of rare earth elements (REEs), are currently disposed of in landfills. This situation is about to change thanks to a new, selective process — developed by Rhodia (Paris, France; www.rhodia.com) — that recovers the REEs from the luminescent powders. The process will be utilized at Rhodia's facilities in Saint-Fons and La Rochelle, France, which will produce several thousand tons of REEs per year when operational in the first quarter of 2012.

In Rhodia's process, the mixture of rare-earth metals is recovered as a concentrate by a combination of hydrometallurgy (selective dissolutions, precipitations and filtrations), and a high-temperature pyrometallurgical process. Individual REEs are then separated from each other by liquid-liquid extraction. The purified metals can then be reused as raw materials for making new phosphors for lamps.

Rhodia says the global demand for REEs is experiencing a growth rate of more than 6%/yr, and this recycling initiative opens the way for new sources of REEs tailored to the market needs. (For more on rare earth metals, see *CE*, October 2010, pp. 17–23).

NANOPARTICLE (*Continued from p. 13*)

ratio. The solution was then added to ethylene glycol containing PVP (poly(N-vinyl-2-pyrrolidone)) at 170°C. After cooling to room temperature, the nanoparticles were separated using a centrifuge.

Kitagawa's group showed that Ag-Rh solid-solution alloys absorb hydrogen, reaching a maximum absorption at a 1:1 Ag-to-Rh ratio, where the alloy's electronic structure is similar to that of Pd. The amount of hydrogen absorbed, 0.09 H/M ($M=Ag_{0.5}Rh_{0.5}$) at approximately 100 kPa, is about half of the capacity for bulk Pd. Kitagawa is now searching for less-expensive metal combinations for industrial applications using the new procedure.

The Kitagawa group also succeeded in creating several rare-earth-metal substitutes, and envisions the development of new solid-solution alloys of immiscible silver-nickel, gold-rhodium, copper-ruthenium and others that exhibit phase-segregated structures, even in the high-temperature liquid phase.

(*Continued from p. 12*)

come up with a novel strain, capable of efficiently consuming both sugars simultaneously. Use of the strain could help realize significant cost savings in bioethanol production.

New rocket fuel?

Chemists at the Royal Institute of Technology (KTH; Stockholm, Sweden; www.kth.se) have discovered a new molecule — trinitramid — that may be suitable as a component for future rocket fuels. Containing only nitrogen and oxygen atoms, the molecule would not only be more environmentally friendly — today's solid rocket fuels release 550 tons of HCl for each space-shuttle launch — but would also boost the fuel efficiency by 20–30%, says Tore Brinck, professor of physical chemistry at KTH. "A rule of thumb is that for every 10% increase in efficiency for rocket fuel, the payload of the rocket can double," says Brinck.

Trinitramid has the formula $N(NO_2)_3$ and a structure similar to a propeller. The stability of the compound in powder form has yet to be determined.

Torrefaction

Metso Corp. (Helsinki, Finland; www.metso.com) and Bio Energy Development North AB (Umeå, Sweden) have started an industrial-scale development project for the torrefaction of biomass (wood and agricultural residues). The target is an industrial-scale demonstration unit in Örnsköldsvik, Sweden.

Torrefaction is a mild pyrolysis process that converts biomass into "green coal", which can be easily transported and used as a substitute fuel for power generation or for gasification processes. ❏

A new process for high-purity MnO_2

Mesa Minerals Ltd. (Perth, Australia; www.mesaminerals.com.au) has developed an alternative hydrometallurgical method for converting low-grade manganese oxide ores to electrolytic manganese dioxide of high purity for use in alkaline and lithium-ion battery production. The company claims its process consumes about half the energy required by a similarly sized plant using the conventional process. The Mesa process overcomes major drawbacks of the traditional route, which relies on a low-efficiency, highly polluting pyrometallurgical-roast process to reduce the ore at high temperatures (800–900°C). The inefficient method produces large amounts of CO_2, particulate matter and metal ions.

The patented Mesa hydrometallurgical process adds SO_2 gas to an acidic slurry of finely ground manganese oxide ore at below 100°C. The main benefits of the new route are the simplicity of the leach step compared to the conventional pyrometallurgical route, and the ease with which it can be monitored and controlled, Mesa says. The off-gases from the SO_2 leach are predominantly steam, nitrogen and unreacted SO_2, and there is no dust. The process allows an additional benefit — Mesa's SO_2 leach step pre-conditions the plant residues (tailings) and leaves them in a state suitable for further processing into a micronutrient fertilizer product. The company says this maximizes the profitable utilization of the ores, but also reduces plant costs by avoiding the need for longterm tailings impoundment, while creating a second revenue stream. Mesa says the process has been successfully piloted.

Spray drying converts a medicinal cactus into a powder

A process to spray-dry *Aloe vera* for use in the food and cosmetics industry has been developed by GEA Niro (Søborg, Denmark; www.niro.com). The process is expected to offer an efficient and economical alternative to freeze drying, as well as a method of producing a high-quality powder for use in personal care, nutraceuticals and food products.

The *Aloe vera* cactus leaves are first filleted to remove the hard outer shell. The inner tissue is then shredded and milled into a feed that can be atomized. The atomizable feed pulp is heated to less than 50°C and treated with enzymes that break down the cellulose chain. In this way, the viscosity is reduced. The fibers are then segregated, and those less than 200 microns continue in the process. Aloin is extracted, which can be used as a bittering agent in beverages or as a laxative, and the remaining pulp is pasteurized into a gel. After evaporation to increase the solids content, the gel is spray-dried into a free-flowing powder. ■

COAL-TO-CHEMICALS

This may be coal's decade, as the number of gasification projects skyrockets

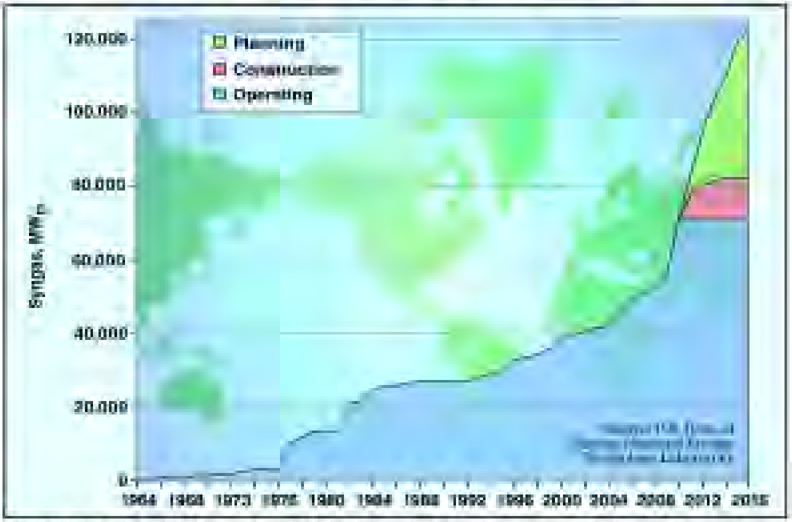


FIGURE 1. Synthesis gas (syngas) production has been surging in recent years, and is projected to increase even more as new projects begin to come onstream

Current industry syngas output has increased by 28% since 2007 — and by 50% since 2004 — reaching a current gasification capacity of 70,817 MW_{th} of syngas output, according to the U.S. Dept. of Energy's (DOE; Washington, D.C.; www.energy.gov) 2010 Worldwide Gasification Database. With 48 new plants (93 gasifiers) planned or under construction in the period 2011–2016, the global syngas production capacity will increase an additional 72% from 2010 levels (Figure 1), forecasts the database, which was published online last December by the DOE's National Energy Technology Laboratory (Pittsburgh, Pa.; www.netl.gov).

Such unprecedented growth is not only good news for companies with gasification technology, but also for industrial gas companies that supply the air-separation units (ASUs) needed to deliver oxygen to the gasifiers, and the firms offering process technology to clean the syngas and convert it to products.

Syngas is used for a wide variety of products, from power generation and liquid fuels, to hydrogen, ammonia, substitute natural gas (SNG) and chemicals (Figure 2). Chemicals hold the lead position, accounting for 45% of the products from syngas, and coal-to-chemicals (CTC) is showing the greatest growth, especially in China, where a number of projects are just starting up in 2010–2011. [For more on coal-to-liquids (CTL) and coal-to-SNG, see *CE*, February 2007, pp. 18–21 and *CE*, August 2010, pp. 14–17].

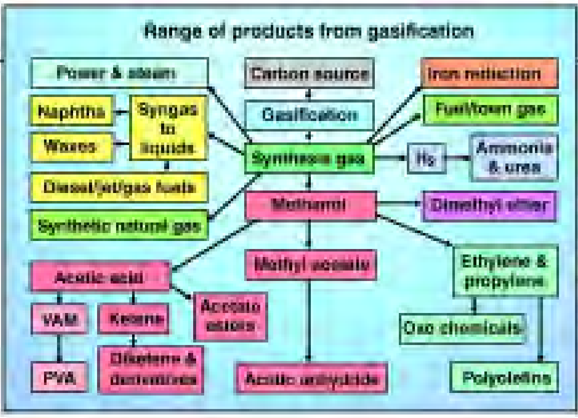
A proven technology

Making chemicals from syngas is not new; Eastman Chemical Co. (Kingsport, Tenn.; www.eastman.com) has been doing so since 1983, when its integrated chemicals-from-coal facility started operations. At Kingsport, approximately 1,300 ton/d of Appalachian coal with relatively high heating value and high sulfur content is processed into a variety of chemicals. The coal is first gasified into raw syngas, a mixture of pimarily H_2, CO and CO_2. The syngas is then cleaned via a Rectisol process that removes CO_2 and more than 99% of the sulfur, which is subsequently recovered and sold as a byproduct. The cleaned syngas emerges as two streams — one a mixture of CO and H_2 and another rich in CO — that are subsequently converted into methanol and methyl acetate (intermediates) and acetic acid and acetic anhydride, the final products. The two liquid products are used throughout the rest of the Eastman plant for making chemicals and plastics found in common consumer products.

Eastman's complex uses gasification technology licensed from Texaco and was the first commercial application of Texaco's gasification technology. [Texaco's gasification technology was acquired by GE Energy (Atlanta, Ga.; www.ge.com) in 2004.] Over the past decades of operation, Eastman has further developed and improved the gasification process so that today, it is operating at 150% of the original nameplate capacity, says Bill Trapp, director of Chemicals Development Division at Eastman.

Setbacks for U.S. projects

In 2007, Eastman announced plans for a $1.6-billion plant for producing syngas from petroleum coke in Beaumont, Tex. (*CE*, September 2007, p. 14). At that time, the project made sense because oil prices had risen dramatically. But the project was subsequently cancelled in 2009. Eastman exited the project, says Trapp, for several reasons, including the rise in construction costs just before natural gas prices fell, the recession and uncertainty in the regulatory process (penalties or incentives for CO_2 capture). "The uncertainty about CO_2 is one of the most significant impediments to project implementation [in the U.S. today]," he says. "Is CO_2 capture required for all projects, at what level, will there be penalties or incentives, how long will they last, who owns the pore space rights in saline aquifers or EOR (enhanced oil recovery) fields, will environmentalists challenge or



Source: Eastman Chemical Co.

FIGURE 2. Syngas can be used for making a variety of chemicals and liquid fuels, as well as for iron making and synthetic (or substitute) natural gas

support gasification projects, and so on. The [U.S.] government needs a clear, permanent strategy that encourages development of the technology (incentives) until the technology matures and can stand on its own," says Trapp.

In contrast to the U.S., China is moving full-speed ahead with coal-to-chemicals. China has definitely taken the lead in new gasification plants, says Trapp. Although the reasons are complex, it boils down to lower cost, captive growing markets and a political will — a clear and determined national policy to drive development of its coal resources, he says.

Such thoughts are echoed by Ron Gualy, vice president technology, coal monetization at KBR Technology, a business unit of KBR, Inc. (Houston; www.kbr.com), who cites uncertainty surrounding potential state regulations relating to greenhouse gas emissions as one of the reasons for the cancellation of a major integrated gasification combined cycle (IGCC) project in Orlando, Fla. Permitting for coal-related plants is very problematic in the U.S. at the moment. "In the U.S., it takes 4–5 years to build a plant, whereas in China projects are being built in 2–3 years," say Gualy.

China's CTC boom

Thanks to its long-term plans to utilize its coal resources, China is the place to be for CTC projects. And a number of major chemical firms are investing in the boom. In 2007 for example, Celanese Corp. (Dallas, Tex.; www.celanese.com), opened its largest integrated chemical complex in Nanjing, China. The complex features a 600,000 metric ton (m.t.) per year acetic acid plant, which receives its CO supply from Wison (Nanjing) Chemical Co.'s coal-gasification plant. Wison also produces methanol from the syngas produced at the Nanjing Chemical Industry Park. More recently (last November), Celanese announced plans to build two 400,000-m.t./yr plants in China for producing industrial-use ethanol, as well as a 40,000-ton/yr ethanol plant in Clear Lake, Tex. Whereas the U.S. plant will use natural gas as its primary raw material, the Chinese plants will use coal. All three ethanol plants will utilize a new process recently developed by Celanese.

Celanese's ethanol process is not based on the fermentation of carbohydrates or sugars, but utilizes basic hydrocarbons, such as coal, natural gas or petroleum coke (petcoke). The process integrates elements of Celanese's other acetyl technologies, and is highly selective to ethanol.

Also last November, The Dow Chemical Co. (Midland, Mich.; www.dow.com) and the Shenhua Group (Beijing, China; www.shenhuagroup.com.cn) submitted a Project Application Report (PAR) to the Chinese government for its approval to build and operate a world-scale, integrated complex of coal, power and chemicals in Yulin city, Shaanxi provence. Submission of the PAR is a step forward for the project that the two firms announced in May 2007.

MTO moves forward

Meanwhile, 2010 marked the first commercial applications of two methanol-to-olefins (MTO) processes, which is a step towards making polyolefins from coal. Last July, Total Petrochemicals (Brussels, Belgium; www.totalpetrochemicals.com) successfully started up its MTO demonstration project at its research center in Feluy, Belgium. The €45-million MTO demonstration plant integrates an Olefin Cracking Process (OCP), developed by Total and UOP (Des Plains, Ill.; www.uop.com), that is integrated in the MTO process, which was developed by UOP and Hydro (for

TABLE 1. PROJECTS USING THE OMB PROCESS					
Status	Start-up	Owner/Name	Capacity (ton/d of coal or petcoke) of single gasifier	No. of Gasifiers (operation + spare)	Product
Operating	2005	Hualu Hengsheng Chemicals Co./Hualu Hengsheng Chemicals Co..	750	1	NH_3
Operating	2005	Yankuang Group/Yankuang Cathay Coal Chemicals Co.	1,150	2+1	MeOH, Power
Operating	2007	Yankuang Group/Yankuang Lunan Fertilizer Plant	1,150	1	NH_3, MeOH
Operating	2009	ENN Group/Fenghuang Fertilizer Plant	1,500	2+1	MeOH
Operating	2009	Jiangsu Linggu Chemicals Co./Jiangsu Linggu Chemicals Co.	1,800	1+1	NH_3
Operating	2009	Jiangsu Sopo Group/Jiangsu Sopo Group	1,500	2+1	MeOH
Operating	2010	Shenhua Ningxia Coal Group/Shenhua Ningxia Coal Group	2,000	2+1	MeOH
Operating	2010	Ningbo Wanhua Co./Ningbo Wanhua Co.	1,200	2+1	MeOH, NH_3, H_2
Development	hold	China Huadian Power Group/Hangzhou Banshan Power Plant	2,000	1	Power
Development	hold	Shandong Jiutai Co./Shandong Jiutai Co.	2,000	6+2	MeOH
Construction	2011	Shanghai Huayi Group Company/Anhui Huayi Chemicals Co.	1,500	2+1	MeOH
Construction	2011	Shandong Shengda Co./Shengda Ningdong Chemicals Co.	2,000	2+1	MeOH
Development	hold	Valero Energy Corp./Port Arthur Refinery	2,500	4+1	H_2
Construction	2011	Yankuang Group/Yankuang Xinjiang Coal Chemicals Co.	1,500	2+1	NH_3, MeOH
Construction	2012	Shanghai Huayi Group Co./Shanghai Coking & Chemical Corp.	2,000	1+1	MeOH
Construction	2012	Inner Mongolia Rongxin Chemicals/Inner Mongolia Rongxin Chemicals	2,500	2+1	MeOH
Development	2013	China Oceanwide Group/Chia Oceanwide Baoto Coal Chemicals	1,500	2+1	MeOH
Development	2013	Shandong Haili Industrial Group/Shandong Haili Chemicals	2,000	1+1	NH_3
Development	2013	Yingde Gases/Yingde Gases in Anyang	2,200	1+1	NH_3
Development	2013	Henan Xinlianxin Fertiliser Co. /Henan Xinlianxin Fertiliser Co.	1,200	2+1	NH_3

Note: All of these projects are in China using coal-water slurry as feed, except for the Valero project, which is in the U.S. and would use petcoke-water slurry as feedstock

Source: Institute of Clean Coal Technology, ECUST

more on OCP and the UOP/Hydro process, see *CE*, January 2006, p. 13).

Total signed a letter of understanding (last November) with China Power Investment Corp. to study the construction of a world-scale petrochemical plant in coal-rich Inner Mongolia. Both firms are now doing feasibility studies on a 1-million ton/yr polyolefins production site, based on methonol produced from coal gasification. The estimated €2–3-billion project would start production after 2015.

Last August also saw the startup of Shenhua Group's Demonstration Coal-to-Olefin Project in Baotou, China. The project plant has a production capacity of 600,000 ton/yr of lower olefins. At the Baotou plant, coal is gasified (using GE's gasification technology) into syngas, which is cleaned and then converted into methanol. The methanol is subsequently converted to ethylene and propylene using the proprietary DMTO (DICP methanol-to-olefin) process, developed by he Dalian Institute of Chemical Physics, Chinese Academy of Sciences (DICP). This is the first commercial application of the DMTO process (*CE,* January 2009, p. 13).

Gasification made in China

Another "home-grown" technology that is making a major impact on China's CTC industry is the relatively new gasification process from the Institute of Clean Coal Technology at the East China University of Science and Technology (ECUST; Shanghai; www.ecust.edu.cn). Developed during the 1990s, ECUST's Opposed Multi-Burner (OMB) gasification technology was first demonstrated in 2005, with the startup of two OMB units handling 750 and 1,150 ton/d of coal. Since then, OMB gasification technology has been selected for 20 projects that are either operating, under construction or in the development phase (Table 1). The most recent contract was signed just last month, says Zhijie Zhou, associate professor at ECUST, adding that the OMB process is also under consideration for several projects with western chemical firms.

ECUST's first license of the OMB process for a U.S. firm — a 2,500 ton/d petcoke gasifier for making H_2 for Valero Energy Corp. (San Antonio, Tex.; www.valero.com) — is one of the three "on hold" projects in ECUST's growing reference list. Reasons for halting the Valero project are similar to those cited above for other U.S. coal-based projects.

The OMB process (Figure 3) features four injectors for injecting a coal-water slurry (CWS) into the gasifier. The key is controlling the gasification process, which is done by mixing, explains Zhou. Four pre-film burners located at the top part of the reactor simultaneously inject CWS and oxygen into the gasifier. The impinging flow from the opposed injectors enhances mass and energy transfer to ensure the gasification reaction occurs instead of combustion. The residence time is only a few seconds. Also, the use of four burners — each performing part of the gasification — makes it possible to increase the capacity of a single unit, says Zhou.

Utilizing low-grade coal

In China there's a lot of lignite and high-ash coal, which is typically unsuitable or uneconomical for operation in commercial gasifiers, says KBR's Gualy. Traditional gasifiers don't work as well if there's a high ash content

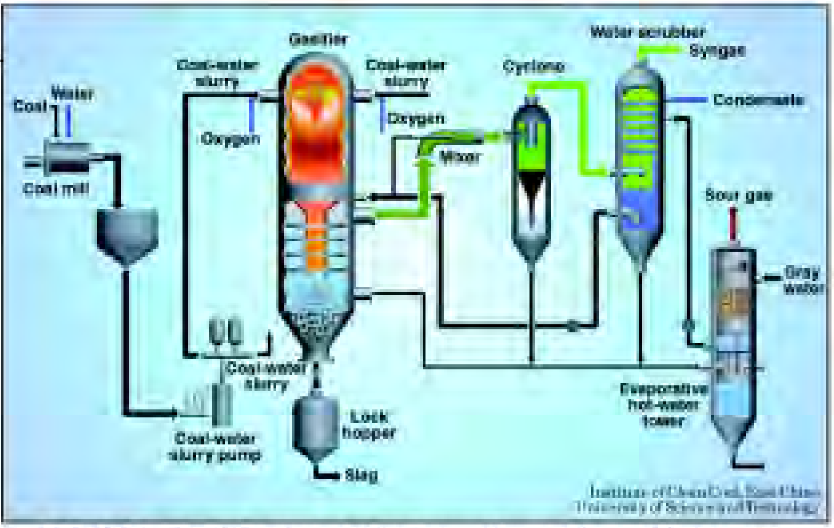


FIGURE 3. The OMB process features opposed burners for gasifying coal-water slurries. Since the process was first commercialized in 2005, it has been selected for 20 coal-gasification projects (see Table 1)

and require extensive drying for high moisture coals. Yet the trend is to use lower value coals — coals that aren't widely traded. As a result, Chinese mining companies are the ones involved in many of the coal-gasification projects, and it's a "mine-to-mouth" approach — building the gasifier plant next to the coal mine, says Gualy. "If you can use low-rank coal at \$10–20/ton to get the same quality product that is achieved from high-rank coal, then the company will have a very competitive product," he says.

"We, too, see an increasing trend to utilize low-rank coals with high ash contents or high ash melting points for gasification applications, as well as the entire biomass spectrum," says Karsten Radtke, head of Gas Technologies Division, Uhde GmbH (Dortmund, Germany; www.uhde.eu). "Lower quality coals come with lower market prices and make gasification a more attractive, viable solution." These lower quality coals are indeed opening new regions for gasification applications, such as India, South East Asia and Australia, but also the residual coals (culm or fines) in the U.S. or Africa. Biomass is a dominating topic for the industrialized countries such as in Western Europe or the U.S., says Radtke.

Gasification technologies have to adjust to these new, lower quality coals as well as to address the new CTC/CTL product target, explains Radtke. "One trend we have seen is a revival of fluidized-bed gasification processes, such as the High-Temperature Winkler (HTW) process, which can handle low-rank coals with high ash melting points, biomass and wastes."

Last month, after 35 years of collaboration with RWE on the HTW process, Uhde took over the technologies developed by RWE Power AG (Essen, Germany; www.rwe.com) and its predecessors. This makes Uhde the sole proprieter of the HTW process, including intellectual property (IP) rights know-how and patents.

"The HTW fluidized-bed gasification technology perfectly complements our Prenflo entrained-flow process, since it widens the feedstock spectrum for Uhde's gasification business. Uhde now has in the HTW process a coal gasification method that is particularly suited to lignites, hard coals with a high ash melting point and biomasses, such as wood, peat and even household waste. We expect a specific market growth for these types of feedstocks in the near future," says Radtke. Among its many projects, Uhde is currently working on a new engineering contract for an HTW gasification plant for VärmlandsMetanol AB (Hagfors, Sweden). The proposed plant would produce 100,000 ton/yr of fuel-grade methanol from wood.

Biomass is an important feedstock for gasification applications, mainly because of the CO_2 neutrality, and the relevant political drivers, explains Uhde's Radtke. He agrees that the main hurdles that biomass has to overcome are the logistical and infrastructural challenges. A suitable biomass pretreatment, such as torrefaction, will have to be employed, following the principle of decentralized biomass

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gathering and pre-treating, combined with a central biomass gasification — such as the direct quench version of Uhde's Prenflo gasifier, PDQ, as currently planned for a biomass-to-liquids facility in France. This way, the central gasification plant can make use of the economy of scale, explains Radtke.

KBR is also targeting low-rank, high-ash coal applications with its transport integrated gasification (TRIG) technology. Developed together with Southern Co. (Atlanta, Ga.) for handling low-grade coals, TRIG was first demonstrated ten years ago. KBR is now working on the first commercial applications of TRIG — a 120-MW IGCC power plant in China, scheduled for completion in 2011; a CTC application in Inner Mongolia scheduled for completion in 2012; and a 582-MW IGCC plant, scheduled for completion in 2014. The third project is being developed in Kemper County, Miss., and will be owned and operated by Mississippi Power Co. (Gulfport, Miss.).

TRIG technology includes a refractory-lined, circulating-bed gasifier that uses a dry feed and operates at temperatures below the melting point of ash (*CE*, November 2009, p. 13). The dry feed is advantageous for another emerging application for TRIG, namely gasification of wood or mixtures of biomass and coal. The main problem with biomass is logistics. The success of the projects depend primarily on the companies' ability to collect economically sufficient biomass feed to operate a gasification project in large enough scale to make it profitable, says Gualy. "We see a lot of interest in coal-biomass mixtures, especially in the U.S. and Europe."

"We've had a lot of activity this past year, and I expect to see several new projects before the first commercial TRIG unit starts up at the end of the year, and many more after the startup," predicts Gualy. KBR is also working on a small demonstration unit in Korea to target later CTC and coal-to-SNG projects.

Another gasification process is ConocoPhillips' proprietary E-Gas Technology, which converts petcoke, bituminous and sub-bituminous coal feedstocks into high-value syngas used for a slate of products, including power, SNG, H_2, and chemicals. The unique two-stage design, continuous slag removal and dry particulate removal features of the E-Gas Technology allow for high efficiency in a compact design, reducing both capital and operating costs, says Chip Troxclair, manager E-Gas Technology, ConocoPhillips (Houston; www.conocophillips.com).

There has been growing interest in gasification of coal and petcoke for the production of SNG, says Troxclair. These projects are typically located where natural gas is not readily available, where large volumes of petcoke are available, near large coal deposits, or where coal or petcoke can easily be delivered, he says.

However, this interest has been dampened somewhat by the growth in unconventional natural gas supplies in the U.S., ongoing uncertainty regarding potential climate change regulations, and challenges to coal use and the timing and role of carbon capture and storage, he adds.

Relative to the E-Gas Technology, ConocoPhillips is now offering a larger, higher pressure gasifier capable of processing up to 3,400 ton/d petcoke and 4,500 ton/d sub-bituminous coal. "We have also developed a new Slag Separator package to further reduce the carbon content in the slag product, and have upgraded our high temperature heat recovery boiler with new design features and materials," says Troxclair.

IHI Corp. (Tokyo, Japan; www.ihi.co.jp) is also targeting low-rank coals for gasification projects for its new twin-tower, bubbling fluidized-bed gasification process (for flowsheet, see *CE*, April 2010, p. 11). The process has the advantage of operating at relatively low temperatures (800–900°C versus 1,400–1,500°C used by entrained gasifiers) and the use of steam instead of oxygen, which increases the H_2 content of the syngas, says IHI.

A demonstration plant that will gasify 50-ton/d of lignite into syngas is due to start up this year in Indonesia. The company plans to offer commercial units with capacities of 300 to 1,000 ton/d of coal. ■

Gerald Ondrey

NO MORE SEPARATION ANXIETY

More robust, versatile and energy-efficient machines can help take the economic stress out of liquid-to-solid separations

FIGURE 1. Alfa Laval's new, modular high-speed separator platform provides versatility and the ability to upgrade or rebuild the separator in the future

Given the state of the still-lagging economy, it doesn't come as a surprise that the chemical process industries (CPI) are attempting to get more finished product from their existing processes at lower costs. As a result, many are examining their liquid-to-solid separation operations with hopes of eking out additional product and savings. And, it appears that more robust and versatile automated equipment may yield the solution.

"We're seeing a lot of customers who want to get more out of existing installations," says Doug Osman, director of life sciences and high-speed separators with Alfa Laval (Warminster, Pa.). "Increasing the yields from fixed batch sizes is called 'specific productivity.' To achieve this goal, processors have to be smarter in the way they process and find ways to make the production yields greater without making the plant bigger."

Robust, versatile equipment

Derek Ettie, director of the process group with GEA-Westfalia Separator (Northvale, N.J.) agrees and says one way to do this is to employ robust equipment. "When it comes to separation operations, people are looking at ROI (return on investment) and economics. The dollar volumes are becoming more and more critical, so we're seeing a lot of cost-driven projects, projects that involve replacing older equipment with more robust versions and projects that focus on better maintenance service."

These days, "robust" equipment not only means that it's mechanically more reliable, but also provides repeatability as far as achieving consistent product quality from every run, Ettie says. In response to the need for this type of equipment, Westfalia and other separator manufacturers are focusing on producing equipment that has better balancing capabilities, reduced vibration levels and improved instrumentation, which allows more precision during processing.

Electronic online monitoring is an option available from providers like Westfalia. "Our 'wewatch' program allows us to plug into our customers' operations and monitor them," says Ettie. "If there's a problem, they can call us and we can read the vibration and temperature monitors and help them troubleshoot. This provides much faster and more accurate resolution to get the line up and running quickly."

Wewatch service is available on robust separators like the Westfalia Separator's "directdrive" models (Figure 2), such as the CSI 500. In these models, the drive is housed directly underneath the bowl in the frame. The main advantage of this technology is the improved efficiency, with higher reliability and availability compared with gear-driven machines, flat-belt machines and conventional direct drives. Lower noise levels and smaller space requirements are also benefits, says Ettie.

Alfa Laval offers a concept known as eDrive drive on some separators. This control function generates energy savings, reduces maintenance costs and improves the robustness of the system since it has fewer parts. The concept combines advanced mechanical and electronic monitoring, with embedded control logic, known as 2Touch. 2Touch provides operational and safety supervision and ensures energy efficiency, cooling and lubrication, which translates into less downtime and greater cost savings for users. The system allows for hardware and software upgrades providing a platform for system improvements as they become available.

Versatility within a given facility, says Osman, is another trend. Processors, especially those in specialty chemicals, are trying to make more products within existing facilities. "Our customers realize that a dedicated facility or process line is not always the most economical option, so they are trying to build in versatility, allowing them to make more than one product on a specific line and switch back and forth between them as needed."

That necessary versatility can be found in separators such as Alfa Laval's new, modular high-speed separator platform (Figure 1). Based on a modular principle and comprising a number of building blocks, the new separators in this range replace the largest self-cleaning separators in Alfa Laval's portfolio.

The modular design makes it possible for those in the CPI to deliver an application-specific product in a shorter time. It will also be easier for users to upgrade and even rebuild the separator in the future, instead of investing in a completely new model because replacing just one block creates configurations with distinctive and upgraded capabilities, according to Osman.

The modular design should also permit faster technology development, since the established interface between blocks make it possible to develop one or a number of the building blocks to create new machines with new functions.

Doing more with less

Processors want to produce more product in less time with the least amount of equipment and want to reduce the number of transfer steps within the equipment, says Dave Altum, process applications engineer with Heinkel (Swedesboro, N.J.). "Our customers are looking for a machine that can filter material, wash it of impurities and dry it all in one step," says Altum.

Doing the bulk of the drying during separation helps reduce the amount of money spent on energy, he notes. For this reason, he says many of his customers are trying to reduce the load on the downstream dryer. "The wetter the material, the bigger the dryer and the more energy used. So, if the amount of moisture can be reduced before the product goes to the dryer, processors can buy a smaller dryer because the bulk density is smaller without the excess moisture, and the energy costs will go down because there is less liquid or solvent to remove."

In addition, a lot of processors are hoping to make the move from a batch to an automated, continuous operation because it's faster and requires fewer transfer steps and less operator intervention, which speeds up production and reduces operating costs, explains Altum.

GEA-Westfalia

FIGURE 2. Directdrive technology houses the drive directly underneath the bowl in the frame of separators, such as the CSI 500, for improved energy efficiency with higher reliability and availability

Heinkel's Inverting Filter Centrifuges provide a suitable solution for processors who find these demands on their wish lists. "This model is the most versatile one we offer. It can separate, wash and dry and is able to handle the most difficult filtering materials," Altum says. "Depending on the product, it may eliminate the need for a downstream dryer; or if one is still needed, it would be a much smaller dryer, which reduces capital and energy costs."

Touted as "fully automated technology for optimum efficiency," the Inverting Filter Centrifuge principle is based on slurry being delivered to the process chamber, which is a rotating drum, via a feed pipe. The filling step is usually controlled through a load-cell based weight-control system.

The drum spins at a pre-set value chosen from the speed range of the individual machine. The filtrate passes through the filter cloth, which lines the process chamber, and the solids collect and build up on the filter cloth to form a cake of material. Wash liquid is introduced and controlled in the same manner as the slurry. Due to the homogeneous cake buildup, each part of the solid cake will be washed to the

SEPARATION SERVICE PROVIDERS

Alfa Laval	www.alfalaval.com	GEA-Westfalia	www.westfalia-separator.com
Andritz KMPT	www.kmpt.net	Heinkel	www.heinkelusa.com
Bayer Technology Services	www.bayertechnology.com	Outotec	www.outotec.com
BHS Filtration	www.bhs-filtration.com	Western States Machine Co.	www.westernstates.com
Flottweg	www.flottweg.com	Wyssmont	www.wyssmont.com
FLSmidth	www.flsmidth.com		

The separated solids are discharged by inverting the filter cloth through the axial movement of the shaft, while the bowl remains rotating at a low speed.

Similarly, Bayer Technology Services (Pittsburgh, Pa.) offers a hot filter press, which combines separation and drying in one apparatus. The process steps include filtration, filter cake washing, mechanical dewatering by squeezing, and thermal drying (using vacuum contact drying) in one piece of equipment. The basic design is similar to that of a normal filter press using one packet of diaphragm plates for the usual filtration, washing and squeezing steps. Hot water, which is sent through the space behind the diaphragm, provides the energy required by the system for drying. At the same time, vacuum is generated via the filtrate lines.

"Different technologies like this are becoming essential as processors are moving toward separation processes that are less energy intensive and more efficient," says Eric Boonstra with Bayer Technology.

In addition, Heinkel's Altum says in this era of doing more with less, processors should consider moving to a smaller machine like the inverting filter. "In an effort to get more product throughput, processors often make the mistake of buying the biggest machine they can, but this is often counterproductive," he says. "Because the size of the load affects the time it takes to process, going this route is often counterproductive. Often putting smaller loads into a smaller machine with faster cycle times will yield a higher production rate."

Whether this works for a particular situation will depend on the physical properties of the product itself, but often a big machine processing a large load will take eight hours to complete the cycle, whereas a smaller machine with a smaller load, which dewaters faster, will require fewer cycles and produce more product in the same amount of time.

While this may be a way to generate more product, GEA-Westfalia's Ettie suggests the opposite tactic for processors who are interested in reducing overall plant costs. "One large centrifuge can replace three smaller ones," he says. "This often equates to fewer operators, less equipment and smaller space requirements, which reduces operating costs." However, he says this will not increase total plant output, so consideration needs to be given as to which goal is the most important in a facility.

Energy & environmental issues

Because most of the products being processed in liquid-to-solid separations are solvent wet, emissions are a concern, not just for the environment but because the solvents are expensive. "Solvents are expensive to buy and volatile organic compounds (VOCs) emissions continue to be a focus," says Osman. "So in addition to the economics of having to replenish solvents, there are environmental concerns as well. For this reason, containment around unit operations is an important issue these days."

Energy efficiency, too, is another issue that straddles both the economy and the environment. Fortunately containment and energy use tend to go hand in hand when it comes to solid-liquid separating equipment, and improvements are being made.

For example, Alfa Laval offers bottom-fed hermetic inlets on some separators to ensure an air-free separation process, eliminating foaming and oxidation of the process liquid, and providing substantial energy savings. Changing from an open to a hermetic inlet can lower the energy consumption of the separator by as much as 40%, according to Osman.

GEA-Westfalia offers a gas-tight

decanter (Figure 3) available as a clarifying decanter and an extraction decanter. The flat-cone CE 345 is a clarifying decanter used for removing solids from media that are exposed to the risk of explosion, such as plant extraction from organic solvents. The steep-cone CE 346 is an extraction decanter used in conjunction with a three-phase mixture involving solvents.

In addition to being gas tight, both models are smaller in size, which offers minimum energy consumption.

And, similar improvements are being made to dryers, which are notorious downstream energy hogs. For example, Wyssmont's Turbo Dryer is a continuous drying unit that operates at atmospheric pressure without vacuum to dry both solvent- and water-wet materials.

"For solvent wet we use a re-circulating sealed system with nitrogen recycle so there's no exhaust of the solvent to the atmosphere," says Joe Bevacqua, vice president of Wyssmont (Fort Lee, N.J.). "The nitrogen is reused and re-circulated and then condenses the solid, which provides a low partial pressure of the solvent in the nitrogen, allowing the equipment to function without vacuum."

The model also offers uniform inside temperature or zoned temperature regions to provide the closest product temperature possible, which provides energy efficiency for the end user.

Because energy-efficient, versatile and robust liquid-to-solid separation equipment can indeed help chemical processors yield more product from their existing lines while spending less capital, it makes good business sense in this tough economic environment to consider the option of updating equipment.

FIGURE 3. GEA-Westfalia's gas tight decanters offer improved separating efficiency, minimum energy consumption, reduced number of components, compact design and optimized service

When size really matters

In the minerals processing industry, large volumes of slurries have to be dewatered, so the bigger the filter press, the fewer units will be required. FLSmidth (Midvale, Utah) is said to offer the largest capacity, fully automated minerals-duty filter presses in the world. Its AFP IV Automatic Filter Presses, for example, have a volume of more than 19.2 m^3, a filtration area of 1,000 m^2, and can operate at up to 15 bars filtration pressure. Such large, single-filtration capacity becomes particularly advantageous in minerals-tailings dewatering applications where multiple filters are required to dewater large volumes of solids, says the firm. The AFP Filters maximize water recovery for reuse in the process, and the resulting cake can be stacked, which reduces the need for tailings ponds, says FLSmidth.

Last December, Outotec Oy (Espoo, Finland) introduced two new members to the Outotec Larox CC Filter family, the Red and Orange Plates. The Orange Plate features a fluorine-resisting formulation, and is designed for processes emphasizing low-cake moisture. The Red Plate filter medium has a monolithic membrane structure with highly porous core, and is designed for processing requiring high capacity, such as ferrochrome applications. ■

Joy LePree

ERIC ABBEY / *OWNER*
LOVING PETS CORPORATION
DECORATIVE FEEDING BOWLS AND PET TREATS
CRANBURY, NJ
SINCE 2005 18 EMPLOYEES

NO SMALL ACHIEVEMENT: SELLING MORE WITHOUT GOING BROKE

CHALLENGE: Eric was enjoying astronomical growth. Orders for the *Bella Bowl™*, the company's top seller, were going through the roof. But demand was putting a strain on Eric's relationship with his supplier, not to mention his cash flow.

SOLUTION: Eric had the Cash Flow Conversation with his PNC banker, who used his manufacturing industry knowledge to tailor a solution to fit Eric's specific needs. They agreed that increasing Eric's line of credit[1] would help keep production lines flowing smoothly — and allow Eric and his team to go out and sell even more, without worrying about cash shortfalls.

ACHIEVEMENT: Loving Pets recently sold more than 330,000 *Bella Bowls™* in a single month — the most ever. Now that Eric's cash flow is steady, he can focus on taking his business to the next level.

***WATCH ERIC'S FULL STORY at pnc.com/cfo** and see how The PNC Advantage for Manufacturers can help solve your business challenges, too. Call 1-877-535-6314 or visit a PNC branch to start your own Cash Flow Conversation today.*

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Crow's nest

The fact that I was 150 ft up, on the outside of an extraction column, in January, in Canada, in a 20-mph wind, was not the worst part of the experience. The worst part was that the column was not working properly, and I had helped to design it.

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

Like most industrial columns, this one had vertical ladders on its side. Each ladder led to a landing, or so-called deck. Each ladder was surrounded by a cage. The cage was designed to stop a falling human from reaching the ground. The cage included vertical open slots that were about 10-ft long. If a climber wanted to, he or she could place a leg or an arm through these slots, but an entire body would not fit through.

My colleague, George, and I were members of an eight-engineer troubleshooting team that was working on location at the plant for two months. Because George and I were the junior people on the team, we were assigned the midnight shift of midnight to 8:00 a.m. One of my duties each shift, was to climb the extractor and record data all the way up. These data included temperatures, pressures and level-glass readings. Very near the top of the extractor was a pressure gage that was particularly difficult to read.

On one particularly cold night, I bundled up as usual, including gloves. I took my flashlight. I took my note pad. I climbed the ice cold column in the frigid air. All went well until I reached the top pressure gage. At some time during the last 24 h, a crow had decided to start to build a nest in a warm area behind the gage. I was unaware of its presence. I pulled my flashlight from my coat. I shined it at the gage. The crow was startled and flew right at me. I was startled and instinctively jumped backward off of the ladder. Falling 150 ft might have been better than what happened next. One of my legs went through a vertical slot in the cage. The other leg stayed inside the cage. I fell about 8 ft until my groin impacted — forcibly — a horizontal support band that held the cage together. Men who have been kicked "there" know what it feels like. Falling onto that support band was the equivalent of being kicked simultaneously by four irate roller-derby queens, all with pointed shoes.

The column control room was not far from the column, but, the room's concrete walls were very thick. Nevertheless, some operators might have heard my scream through the walls. None came to help me, which I wonder about to this day.

I extracted myself slowly from the cage. I climbed gingerly down the column. My groin was on fire. I did not feel the cold. I shuffled to the control room and told George and the operators what had happened. The operators thought the incident was funny. George pretended to feel sorry for me. I gave George the data that I had collected from the column before the crow "got me". I abandoned the rest of my shift and ended up under the covers at the local Holiday Inn.

I am happy to say that just a few years later my wife gave birth to two sons within a period of less than 12 months. Both were born normal — almost.

Decades later, the lessons to be learned are several. Wear your safety harness. Let your colleagues know where you are. And last, but not least, expect the unexpected. ■

Mike Resetarits
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CHEMICAL ENGINEERING
FACTS AT YOUR FINGERTIPS
Department Editor: Scott Jenkins

Control valve position sensors

The precise monitoring and control of valve position is essential for efficient automation of both discrete and continuous processes. Measurement of valve position provides the data required for the use of advanced control strategies and predictive maintenance algorithms.

More effective monitoring of valve position has been an area in which considerable progress has been made in improving the performance and reliability of control valves. Modern electrical valve-position indicators offer either mechanical or non-contact switching. The position indicators are typically mounted either directly on a valve actuator or work indirectly using a non-contact remote feedback device.

Mechanical switches

Most mechanical-switch valve positioners (Figure, top left) utilize some type of rotary potentiometer for converting linear to rotary feedback. These widely used devices are similar to variable resistors.

Rotary potentiometers have an arched coil of wire, over which an arm, called a wiper, slides. The wiper is attached to the valve cam shaft, and as it moves across the coil of wire, a differing voltage output is produced. The voltage output is proportional to the angle at which the wiper is oriented.

Mechanical switches include contact linkages that are subject to wear over time. The wear can eventually degrade performance.

Non-contact proximity positioners

Non-contact technology approaches to valve positioning can provide accurate valve-position data without the need for the linkages or levers required by traditional systems. Avoiding mechanical contact in the valve positioning system addresses some of the performance and cost challenges associated with control valves, including mechanical wear, environmental hazards, human error and inaccurate readings.

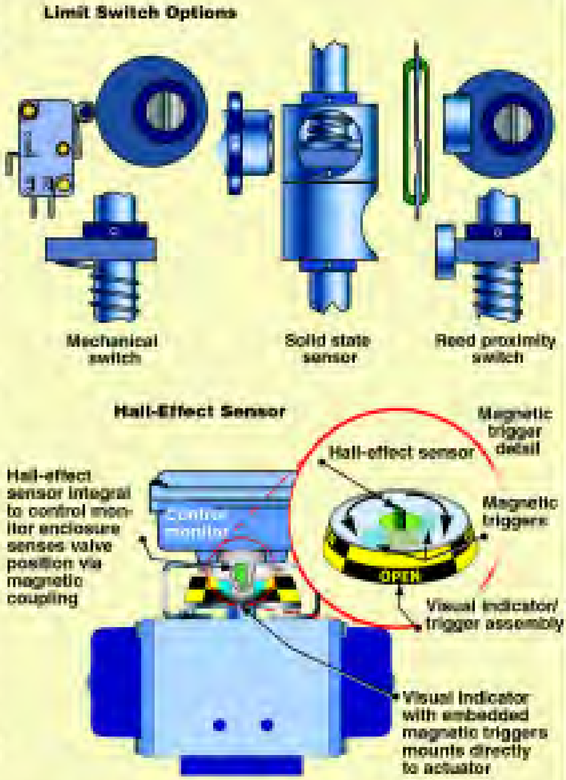
Many non-contact proximity positioners (Figure, top right) incorporate a control-loop feedback mechanism based on an analog PID (proportional integral derivative) algorithm that has been updated for a digital device. The algorithm incorporates the Ziegler-Nichols (Z-N) tuning procedure, a well-known method for tuning automatic controllers. It is a two-step tuning approach that adjusts how agressively the valve controller reacts to errors between the process variable and the desired setpoint.

Hall-effect sensors

A number of non-contact proximity positioners are based on the solid-state Hall effect, and are used to help improve monitoring and control of production processes. The Hall effect refers to a potential difference, known as the Hall voltage, between opposite sides of an electrical conductor through which an electric current is flowing. The Hall effect is created when a magnetic field is applied perpendicular to the current direction.

A sensor using the Hall effect is a transducer that returns a voltage output according to changes in the magnetic field. For valve position sensing, an integrated Hall-effect sensor and magnet assembly detect the presence, absence and orientation of a magnetic trigger. The sensor is powered by a constant current, and develops a varying electrical potential that is proportional to the flux density of a magnetic field applied perpendicular to the axis of the sensor.

Hall-effect proximity sensors used for valve positioning offer increased reliability in extreme environments. These sensors eliminate all mechanical contact between the valve actuator and the transmitter. Because there are no moving parts within the Hall-effect sensor and magnet, the life expectancy is improved compared to a traditional electromechanical switch.



Reed switches

Some non-contact valve positioners are based on reed switches. A reed switch is an electrical switch that is operated by an applied magnetic field. Reed switches have a pair of electrical contacts on ferrous metal reeds in a hermetically sealed glass envelope. An applied magnetic field moves the reeds, causing the contacts to either touch or move apart. The contacts can either be open normally, closing when a magnetic field is present, or closed normally, opening in the presence of a magnetic field. Bifurcated reed switches can be used in applications where ultralow power or capacitive discharge consideration are in effect.

Benefits

Significant benefits for non-contact valve positioners, include the following:

Greater flexibility — Non-contact positioners utilizing Hall-effect sensors provide feedback on valve position without linkages, levers or rotary or linear seals. This allows a remote sensor-head assembly to be mounted a considerable distance from the electronics enclosure, giving engineers increased flexibility and improved safety.

Improved reliability — Safety integrity level (SIL) ratings are higher with non-contact sensors and low-power solenoids. SILs are a measure of safety system performance. Higher SIL numbers mean better safety performance and higher confidence in the field device.

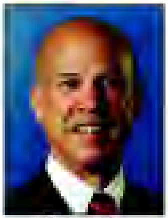
Lower costs — Non-contact valve positioners have a lower overall total cost of ownership than conventional devices, thanks to the precise positioning capabilities that can be customized by valve application. Also, the cost of ownership is lowered by ease of calibration and service, and rich diagnostics for predictive maintenance signatures.

Increased versatility — Non-contact valve positioners are designed to be compatible with most standard industrial communications protocols, including HART, Foundation Fieldbus, AS-I, Modbus, DeviceNet and Profibus. These devices can help engineers take advantage of the cost savings and increased diagnostic capabilities of networks, along with the advantages offered by improved position sensors.

Notes

This edition of "Facts at Your Fingertips" was adapted from Jack DiFranco's article, entitled Advances in Valve Position Monitoring, that appeared in the December 2007 issue of *Chemical Engineering*, pp. 46–50.

WHO'S WHO


Atanasio


Bloom


Brandt


Feng


Mirgel

John Atanasio becomes president and CEO of **Alfa Laval USA** (Richmond, Va.).

Engineering and construction firm **Integrated Project Services** (Lafayette Hill, Pa.) welcomes *Robert Roy*, senior consultant, *Jason Collins*, senior process architect, and *Louis Isernia*, project manager, to its Advanced Aseptic Technologies Group.

MAC Equipment (Houston), a provider of pneumatic conveying and air filtration solutions and division of Clyde Process Solutions plc, names *Jan van Bakergem* global industry director for petrochem.

George Prest becomes chief operating officer of the **Material Handling Industry of America** (Charlotte, N.C.).

Archer Daniels Midland Co. (ADM; Decatur, Ill.) names *Paul Bloom* business director to develop and commercialize renewable chemicals and to manage the commercial activities of ADM's industrial chemicals business.

Henri Azibert, chief technology officer for the **A.W. Chesterton Co.** (Woburn, Mass.) has been appointed to the board of directors of the Fluid Sealing Assn. (Wayne, Pa.).

Bayer MaterialScience LLC (Pittsburgh, Pa.) has appointed *John Brandt* head of coatings, adhesives and specialties (CAS) in the NAFTA region, *Sharon Feng* vice president of business development for CAS, and *Volker Mirgel* senior vice president of CAS. ■

Suzanne Shelley

FOCUS ON

Analyzers

JM Science

Emerson Process Management

Electro-Chemical Devices

A conductivity sensor for high T, P applications

The model CSX2 conductivity sensor (photo) is designed for temperatures up to 200°C at pressures of 250 psig. For temperatures below 100°C, the CSX2 is rated for pressures of up to 400 psig. The CSX2 is a two-electrode sensor that measures electrolytic conductivity in the range of 1.0–50,000 μS (S = Siemans). It has a outer body made from 316 stainless steel, and its center electrode is separated by a PEEK (poly ether ether ketone) insulator. The CSX2 is suited to harsh processing environments in petroleum refining, electric power generation, metals and mining, and any application using high-pressure steam boilers. — *Electro-Chemical Devices, Irvine, Calif.*
www.ecdi.com

Generate less waste with this mercury sensor

The Aquacounter HG-400 low-cost mercury analyzer (photo) requires small sample sizes and minimal reagents, so it generates a small volume of waste in sampling. Its detection limit is 0.5 ppt at sample volumes of 5 mL, and 5 ppt at sample volumes of 20, 100 and 250 mL. The mercury detector can be used to analyze trace mercury levels in effluent treatment application, and can also be used to detect trace mercury in food, ambient water, or as an impurity in copper and other metals. — *JM Science Inc., Grand Island, N.Y.*
www.jmscience.com

Save space with this benchtop NMR machine

The second-generation MQC benchtop nuclear magnetic resonance (NMR) analyzer features improvements that help maximize laboratory bench workspace. It has a more compact size and an internal computer with operator interface, so no external PC is required. The MQC's magnet, computer and electronics are contained in two separate housings, making it possible to place the electronics on the floor below the bench or on a shelf above. In addition to the space-saving improvements, the new version of the MQC also features interchangeable probes that allow different sample sizes, including a new liquid variable temperature probe, and a small magnet that can generate a very homogeneous field. The MQC can be used for determining oil content in seeds, foods, wax and rubber, and can help check quality in construction materials and personal care products. — *Oxford Instruments America Inc., Concord, Mass.*
www.oxford-instruments.com

This transmitter is ideal for monitoring hard-to-reach locations

With a weatherproof and corrosion-resistant cast-aluminum enclosure, the Model 6081 transmitter (photo) is ideal for monitoring applications in hard-to-reach or cost-prohibitive locations. The 6081's measurement capabilities include pH, conductivity, resistivity, total dissolved solids and oxidation-reduction potential (ORP). Upon installation, the unit will auto-locate the most efficient communication path to the host, and will begin transmitting measurement data via 2.4 GHz wireless communications. — *Emerson Process Management, Rosemount Analytical, Irvine, Calif.*
www2.emersonprocess.com

This combustion gas analyzer simplifies operation

Designed for oxygen analysis in combustion gases, the Endura AZ20 (photo, p. 29), can handle tough environments in the hydrocarbon-processing, power-generation and chemical process industries. The instrument features self-diagnostic electronics and integrated automatic calibration, as well as a construction that simplifies access to components for complete site serviceability. The Endura AZ20 is available with probe lengths up to 4 m, and with industry-standard flange configurations. — *ABB Automation Products GmbH, Alzenau, Germany*
www.abb.com

Note: For more information, circle the 3-digit number on p. 54, or use the website designation.

ABB Automation Products

This spectrometer has temperature-controlled optics

Equipped with CCD (charge-coupled device) detector technology, the latest generation of the Spectromaxx Optical Emission Spectrometer features temperature-controlled optics and a benchtop footprint. The instrument is capable of detection limits down to 10 ppm for elements such as nitrogen — the performance most often associated with larger, more expensive stationary instruments, says the company. All measurements are carried out under an argon shield through which a constant flow can be maintained. The new generation instrument has the ability to suspend argon flow while the machine is not in use, and automatically re-establish flow at a predetermined time before work begins again. The Spectromaxx instrument is rugged enough for locations such as furnace cabins. — *Spectro Analytical Instruments GmbH, Kleve, Germany*
www.spectro.com

Cross-correlate UV and IR data with this technology

The Model IPS-4 full-spectrum analyzer performs online measurements of component concentration in the ultraviolet (UV) spectrum using diode-array detection, and simultaneously in the infrared (IR) spectrum using single-beam, multi-wavelength technology. The measurements are then cross-correlated and further verified to avoid interference from complex streams. The IPS-4 can measure up to eight components, using the most favorable absorptions in both the UV and IR spectra. The unit is based on a non-dispersive IR (NDIR) platform, and uses optical components with long lifetimes. — *Ametek Process Instruments, Pittsburgh, Pa.*
www.ametekpi.com

This viscometer features microfluidics technology

The micro-VISC viscosity measurement device utilizes MEMS (microelectromechanical systems) microfluidics technology in a small, easy-to-use instrument. Viscosities from 0.2 to around 5,000 cP can be measured with repeatability within 1%, and volumes of only 100 µL are required for each measurement. The lightweight (1.5 lb) sensor is powered by a rechargeable Li-ion battery, and can log up to 20 tests. Results are displayed in less than one minute for most samples. — *RheoSense, Inc., San Ramon, Calif.*
www.rheosense.com

Calibrate this oxygen sensor with ease

The TR250Z oxygen sensor from this company is designed to lower maintenance costs by simplifying the calibration process. While most oxygen sensors are removed and manually calibrated, the TR250Z instrument can be calibrated in situ with the press of a button, using any gas with known oxygen level. The oxygen sensor can be used in any environment where oxygen depletion may occur, including vacuum test chambers, liquid nitrogen storage areas, enclosed spaces and other workplaces where pressurized gases can displace oxygen. — *CO2meter.com, Ormond Beach, Fla.*
www.co2meter.com ■

Scott Jenkins

Evaluating and Reducing the Risks Of Pneumatic Pressure Testing

Victor H. Edwards, Don Sanford, Brooke Bonstead and **Larry Skoda**
Aker Solutions Americas, Inc.

In applications where pressure testing with liquids is undesirable, the risks of pneumatic pressure testing of pipes and vessels must be evaluated and minimized

The pressure testing of process piping and vessels is essential in the chemical process industries (CPI). In liquefied natural gas (LNG) and other cryogenic facilities, residual water left by hydraulic pressure testing could result in operational problems if not completely removed, and complete removal of residual water can be very difficult and time consuming. Pneumatic pressure testing avoids these problems, and is frequently used for piping and vessels in which moisture is undesirable.

Hydraulic pressure testing with water, however, is much more common than pneumatic pressure testing with a gas because the stored energy of compressed gas can be roughly 200 times the stored hydraulic energy for the test pressures in the range of 100 barg. Therefore, rupture of a piping test system during a pneumatic pressure test can release much more energy. In applications where pressure testing with liquids is undesirable, such as in cryogenic piping systems and vessels, pneumatic pressure testing can only be justified when care in fabrication and in non-destructive examination of vessels and piping reduces the probability of loss of containment to such a small value that risk is acceptable. This article outlines methods for evaluating the risks of pneumatic pressure testing of vessels and piping, as well as methods for risk reduction.

Pneumatic testing

Because the atmospheric boiling point of LNG is approximately –160°C, any residual water left in the equipment, such as by hydraulic pressure testing, is undesirable. Pneumatic pressure testing is therefore frequently used for LNG and other piping and vessels in which moisture must be avoided. As mentioned, the stored energy of compressed gas is very high, so rupture of a piping test system during a pneumatic pressure test can release much energy. Damage due to rupture can result from shock waves, flying projectile fragments from the ruptured piping, and unrestrained movement of piping and equipment propelled by escaping gas. In fact, the cryogenic gas industries have experienced pneumatic pressure testing incidents in the past, sometimes resulting in serious injuries and major equipment damage.

To address the risks associated with pneumatic pressure testing, many companies attempt to limit the amount of stored energy in the test system to a prescribed maximum value by limiting the size of each test system. This approach is often impractical for high pressure piping of typical diameters because of the severe limitation that it places on the size of each test system. Consequently, this approach may result in an unreasonably large number of test systems. Attempting to isolate and test a large number of test systems may prove to be impractical. When the approach of limiting the amount of stored energy becomes impractical, an alternative approach, such as that described herein, may offer the best option. Regardless of which approach is taken, many of the considerations outlined in this article must be taken into account to safely execute high-pressure, pneumatic pressure testing.

A variety of measures can increase the safety of pneumatic testing. Of first importance are measures to ensure the mechanical integrity of the vessels and piping systems undergoing testing. These measures include design, fabrication, and inspection methods. It is also necessary to bar personnel from exclusion zones (an area where personnel are prohibited to enter) surrounding the vessel or piping system under test, and to conduct tests at night or on weekends when few people are in the vicinity of the test site.

Hazards from overpressure

Rupture of a piping system under pressure produces a blast wave. The pneumatic pressure tests planned for the piping systems for one LNG terminal were as high as 121 barg, depending on the class and size of piping under test. Pressures this high can produce a damaging overpressure in the atmosphere within the exclusion zone due to the blast wave or shock wave that results upon rupture of a piping system under test. Lower test pressures can also present significant hazards. For example, rupture of a specific 8-in.-dia. pipe segment at a test pressure of 18 barg could result in a blast overpressure of 0.5 psig (0.0345 barg) at a distance of 28 m.

Overpressure can injure personnel and damage facilities. Overpressure is the localized increase in the atmospheric air pressure associated with the passage of a shock wave.

The overpressure that accompanies failure of a piping system causes harm that is a function of the magnitude and the duration of the shock wave. Typical damaging effects from overpressures are listed below [*1*]:

- 0.4 psig: Limited minor structural damage to buildings
- 0.5 to 1 psig: Glass shattering with body penetrating velocities

TABLE 1. TYPICAL BLAST AND FRAGMENT RANGES FOR PIPING SECTIONS

OD, in.	Wall schedule	Design pressure, barg	Max. test pressure, barg	Selected length of test pipe, ft	Stored energy, MJ	V_{max}, m/s	R_{max}, m	$R_{brittle}$, m	$R_{ductile}$, m	R_{blast}, m	Exclusion zone, m
Carbon-steel pipe											
8.625	STD	19.6	22	57	1.746	68.6	480	192	394	30	30
8.625	XS	91.0	101	57	8.53	123.0	1,543	617	891	47	47
24	STD	19.6	22	88	22.8	109.7	1,228	491	716	69	69
24	80	91.0	101	88	104.0	133.0	1,805	722	1,448	108	108
Stainless-steel pipe											
8.625	20	19.0	21	57	1.751	76.8	602	241	383	29	29
8.625	60	109.8	121	57	10.69	150.3	2,300	922	985	51	51
24	10S	19.0	21	88	22.5	131.9	1,775	710	691	68	68
24	60	99.3	110	88	119.1	156.4	2,500	999	1,614	113	113

Exclusion Zone = The zone within the radius R_{blast}
MJ = mega joules
R_{blast} = Radius within which overpressure exceeds 0.5 psig (0.0345 barg).
R_{max} = Theoretical maximum projectile range based on 100% conversion of released stored energy into kinetic energy [Equation (3)].
$R_{brittle}$ = Estimated maximum projectile range resulting from brittle fracture based on HSE (1998) report.
$R_{ductile}$ = Estimated maximum projectile range of a blind flange resulting from ductile fracture based on Ref. 2.
V_{max} = Theoretical maximum velocity of projectiles based on 100% conversion of released stored energy into kinetic energy [Equation (2)]

- 0.7 psig: Minor damage to house structures
- 1 psig: Partial damage of house structures (made uninhabitable); 95% eardrum protection with ear plugs; People knocked down with potential of significant resulting injuries

Overpressure has the potential to affect most of the nearby area surrounding the piping under test. Therefore, the *minimum exclusion zone* in this work is defined as a zone within a radius beyond which the overpressure from rupture of the piping system under test will not exceed 0.5 psig (0.0345 barg).

Stored pneumatic energy powers the shock wave. Part of the energy that goes into compressing a gas up to the test pressure of a piping system is released suddenly if the piping system ruptures. Several different ways to estimate the theoretical amount of stored energy that is converted into blast overpressure and acceleration of fragments of the ruptured vessel have been proposed. The most common methods of estimating stored-energy release assume isentropic expansion [*1–3*], isothermal expansion [*1,3*], and/or thermodynamic availability [*1,3,4*]. The isentropic expansion model gives the lowest energy-release estimate; the isothermal model gives the highest estimate, which can be as high as twice that for the isentropic model; and the availability model gives an intermediate value [*1*].

Various equations have been developed to estimate the energy release, but most of these equations are based on the ideal gas law. Perhaps the simplest equation was initially proposed by Brode [*5*], and is based on the energy required to raise the pressure of the gas at constant volume from atmospheric pressure to the piping burst pressure [*3*]:

$$E = [(P_1 - P_o)V/(\gamma - 1)] \quad (1)$$

Where E is the energy released upon piping system rupture; P_1 is the pipe burst pressure; P_o is the atmospheric pressure; V is the volume of piping system under test; and γ is the ratio of heat capacity of gas at constant pressure to heat capacity of gas at constant volume.

The ideal gas law is not accurate and is non-conservative for the upper range of planned test pressures, so isentropic fluid-expansion energies based on measured thermodynamic properties of nitrogen gas [*2*] are tabulated in the summary of pneumatically tested piping spreadsheet in Table 1. Reference 2 gives an explanation of the calculation method.

Computation of overpressure from rupture of a piping system. Published methods used to estimate the overpressure of a blast wave produced by rupture of a pressure vessel are usually based on the stored energy of the total volume of compressed gas contained within the vessel. The total gas volume has been used traditionally because the length-to-diameter ratio of the vessel is usually small enough that all of the compressed gas contributes to the blast wave. In contrast, LNG piping systems may have a large length-to-diameter ratio, and only a portion of the piping system near the initial point of failure is expected to contribute to the initial blast wave.

In one project, blast calculations for LNG piping systems were based on the stored energy available in a volume equal to a 40-ft length of pipe plus an additional 24*D* (where *D* is pipe diameter). This assumes a longitudinal seam failure of one 20-ft pipe section (in other words, one single random length). An additional 20 ft were added to account for flow from branches in or adjacent to the failed section, and 24*D* was added to account for flow originating from the header piping adjacent to the failed section. The maximum 20-ft weld-length failure was based on the premise that a propagating crack will stop when it meets the resistance of a circumferential weld. For simplicity, the same volume basis was used to evaluate piping systems fabricated from seamless pipe.

The assumptions stated above with regard to the amount of stored energy in adjacent sections of piping that contribute to overpressure in the exclusion zone and projectile propulsion must be reviewed on each individual project, with consideration given to the physical dimensions and layout of the piping.

An AIChE Center for Chemical Process Safety (CCPS) spreadsheet [*3*], which is based on the method of Baker [*6*], was used to estimate overpressure from rupture of a piping system by gas pressure. Baker's method bases the stored energy of the gas on the Brode equation, as given in Equation (1), but then applies correlations based on experimental data. The resulting exclusion distances to keep overpressures below 0.5 psig (0.0345 barg) are summarized in Table 1 in the column labelled R_{blast}. Overpressures were calculated for maximum test pressures that specific piping systems could experience, as well as lower increments of piping system test pressures.

A representative output from the CCPS/Baker spreadsheet [*3*] is presented in Table 2. The spreadsheet example in Table 2 is for a 36-in., carbon-steel, schedule 80 pipe that has broken at a test pressure of 101 barg. The resulting R_{blast} for an overpressure of 0.5 psig (0.0345 barg) was 156 m. For comparison, the range predicted by Equation (4) (to be introduced later in this article) for fragment range for brittle fracture ($R_{brittle}$) was 908 m.

Exclusion zones were chosen to insure that overpressures from rupture of the piping system could not exceed 0.5 psig (0.0345 barg) at the boundary of the exclusion zone radius, regardless of the mode of fracture of the piping system.

TABLE 2. TYPICAL RESULTS FROM THE APPLICATION OF BAKER'S METHOD FOR ESTIMATION OF BLAST OVERPRESSURE [*3*]

Input data:			
Vessel burst pressure:	102 bar abs	Heat capacity ratio:	1.4
Distance from vessel center:	156 m	Molecular weight of gas:	28
Vessel volume:	18.84 m^3	Gas temperature:	298 K
Final pressure:	1.013 bar abs	Speed of sound in ambient gas:	298 m/s

Calculated results:		
Energy of explosion using Brode's equation for constant volume expansion:		
Energy of explosion:	475 MJ	
TNT equivalent:	101.4 kg TNT	
Effective energy of explosion (X 2):	951 MJ	
Scaled distance:	7.39	
Interpolated scaled overpressure:	0.0244	
Interpolated scaled impulse:	0.00690	
Vessel shape:	**Spherical**	**Cylindrical**
Overpressure multiplier for vessel shape:	1.1	1.4
Corrected scaled overpressure:	0.0268	0.0341
Actual overpressure:	0.0272 bar	0.0346 bar
	0.39 psi	0.50 psi
Impulse multiplier for vessel shape:	1	1
Corrected scaled impulse:	0.0069	0.0069
Actual impulse:	39.3 kPa - ms	39.3 kPa - ms

Hazards from projectiles

Rupture of a piping system may occur due to either ductile fracture or brittle fracture. Under the planned test conditions for one LNG project, it was determined that the carbon-steel systems might exhibit ductile or brittle fracture and that the stainless-steel piping systems might exhibit ductile fracture. The number of fragments and the methods of estimating the velocities of the resulting projectiles differ for brittle and ductile fracture.

Rupture of a piping system under pressure may produce projectiles. Here are Mannan's [*1*] introductory remarks on fragmentation resulting from either brittle or ductile fracture:

"The number of missiles formed in an explosion involving rupture of containment varies widely. At one extreme is the bursting of a weapon such as a high explosive shell or grenade, which normally gives a large number of fragments. Large numbers of missiles are also produced by fragmentation of a gas-filled pressure-vessel. At the other extreme is the ejection of a single item, such as a valve component, due to failure in a high pressure system.

Of particular interest here is rupture of a pressure vessel. This may involve either brittle or ductile fracture. … In general, failure is more likely to be ductile. Ductile failure does not usually produce missiles, but if it does they are likely to be small in number but may have the potential to do severe damage. It is brittle fracture which is most likely to produce failures in which quite a large number of fragments are generated."

Theoretical maximum velocity and range of projectiles. One method of estimating the theoretical maximum velocity is to assume that the pressure energy stored in a piping system is completely converted into kinetic energy of the piping system under test [*2–3*]:

$$E = (m \times v^2)/2 \quad (2)$$

Where E is the energy released upon piping system rupture; m is the total mass of projected piping system fragments; and v is the velocity of each fragment of the piping system.

The theoretical maximum range (neglecting air friction) is then calculated assuming that the projectiles are launched at a 45-deg angle from horizontal. An angle of 45 deg is the optimum angle for the maximum projectile travel distance. Equation (3) is based on Newton's second law of motion and Newton's law of gravitation; its derivation is found in many college-level physics textbooks:

$$R_{max} = v^2/g \quad (3)$$

Where R_{max} is the theoretical maximum range; and g is the acceleration due to gravity. Distances calculated with this conservative method are very large, as can be seen in Table 1. Calculated values range from 35 to 2,497 m.

The Health and Safety Executive (HSE) report [*2*] indicates that only about 40% of the pressure energy would be translated into kinetic energy for brittle fracture of a cylindrical container during testing, and less energy would be translated into kinetic energy for ductile fracture of the container. Thus for brittle fracture, Equation (4) gives a better estimate of the theoretical range of missiles:

$$R_{brittle} = 0.4 \times R_{max} \quad (4)$$

Brittle fracture ranges estimated with Equation (4) are tabulated in Table 1 in the column labeled $R_{brittle}$.

Predicted velocities and ranges of projectiles from brittle fracture. Naturally, most fragments would not launch at the optimum angle, and air friction would reduce the range as well. Finally, when two or more fragments result from rupture of a piping system, the resulting projectiles will usually have a distribution of sizes and initial velocities.

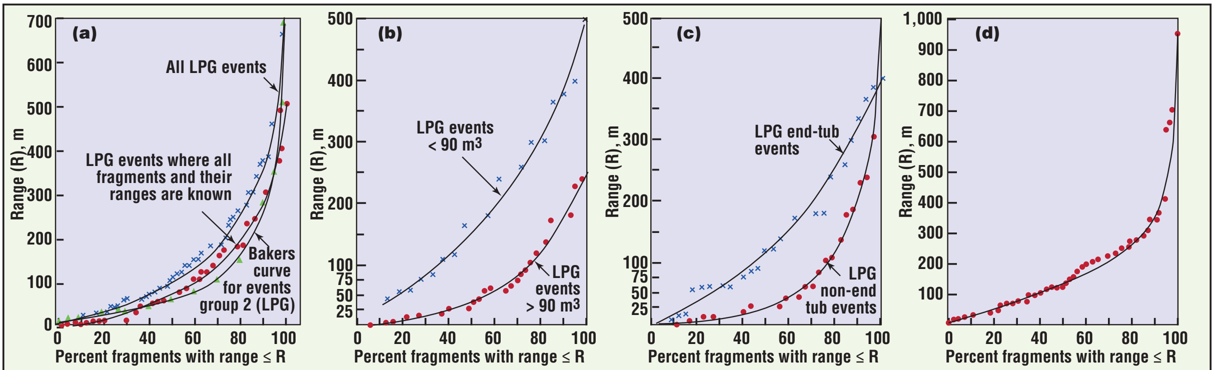
Baker [*6*] developed methods to estimate fragment ranges taking shape and air friction into account. Spreadsheets developed by the CCPS [*3*] to apply these methods were used to develop the results shown in Table 3 for a 20-in., carbon-steel, schedule 80 pipe that has broken into two fragments at a test pressure of 101 barg. Each of the two fragments is a section of pipe, flying end-wise with a lift-to-drag ratio of zero. For comparison, the range predicted by Equation (4) is 709 m. Representative values calculated with Equation (4) in Table 1 are used as estimates of the maximum range of missiles from brittle fracture.

Field data on projectiles from ruptured vessels. Mannan [*1*] pres-

PRECAUTIONS IN PNEUMATIC PRESSURE TESTING

The following are considered essential to minimize the risks of failure and injury during high pressure pneumatic pressure testing:

- Comprehensive testing and safety procedures must be formalized and implemented, and documentation must be maintained certifying that all personnel involved in the testing activities have attended training sessions in which the project procedures have been reviewed. Safety procedures should include requirements that test personnel shelter to the maximum extent possible behind either heavy equipment or barricades during the tests.
- Test procedures must clearly define the points in time during the test when test personnel are permitted to leave sheltered areas and enter the exclusion zone. Prior to proving the system at the full pneumatic test pressure, it is suggested that personnel enter the exclusion zone only when the circumferential stress in the piping is no greater than 50% of the specified minimum-yield strength (SMYS) of the piping materials in the test system, and only after prescribed holding times at such pressures. When the system test pressure results in circumferential stresses that exceed 50% SMYS, test personnel should enter the exclusion zone only after the test system has first been proven for the prescribed time period at full test pressure. Test personnel should never enter the exclusion zone when the test pressure exceeds the piping system design pressure.
- Formalized check lists must be utilized to document that pre-test preparations have been completed.
- Schedule tests at optimum times to ensure safety. The risk of injury resulting from a test system failure can be dramatically reduced by testing at night or on weekends when fewer personnel are on (and possibly off) site.
- Materials must be procured only from manufacturers that have been determined to adhere to suitable, documented quality control and production processes.
- Materials received must be carefully checked to ensure compliance with material specifications (including review of all material test reports received).
- The project must have a suitable positive material identification (PMI) procedure in place that effectively ensures proper materials in the fabricated piping.
- Pressure design calculations for both operating and test pressures must be documented and checked for all piping.
- The use of non-destructive examination (NDE) must be maximized to ensure the quality of all welded joints in the system. Butt welded joints should be 100% ultrasonically or radiographically tested.
- The intended use of "golden welds" (welds that are not proven by pressure testing) to join sections of pre-tested piping must be carefully reviewed to ensure guaranteed quality of the weld joint. It should be noted that some jurisdictions may require approval for their use (such as jurisdictions in which compliance with the European Pressure Equipment Directive is mandated).
- The limits of each test system must be clearly defined in test package documentation, and the methods of isolation (test blinds, and so on) must be well defined. Test blind designs must be checked to ensure suitability for the system test pressures. The proposed design of test systems must be checked by qualified personnel. ❑



Missile effects of explosions: distance travelled by missiles from bursting of LPG vessels (Holden and Reeves, 1985): (a) all events; (b) effect of vessel size; (c) end tub and other fragments; (d) spherical vessels (BLEVEs)

FIGURE 1. Range of missiles from explosions of LPG vessels [*1*]

ents observed fragment ranges from boiling-liquid expanding vapor explosions (BLEVEs) of liquefied petroleum gas (LPG) vessels (Figure 1). Although most fragments traveled 700 m or less, one fragment traveled about 1,000 m (see Curve "d" for spherical vessels). A BLEVE might result in substantially larger distances than a compressed gas explosion of the same container at the same burst pressure. This is because the liquid-filled vessel contains a much larger mass of liquid and a significant fraction of that liquid will vaporize (boiling liquid) upon vessel failure. The vapors will then burn and expand even further. Although the LPG vessels probably failed at pressures well below the test pressure of 100 barg, the BLEVE mechanism may account for the large projectile ranges relative to those expected for pneumatic pressure testing. Although Mannan [*1*] does not indicate the failure mechanism in these incidents, it was probably ductile failure because the LPG vessels failed during external fire exposure.

Figure 2 is a map of the fragment location from a test at Sandia National Laboratories [*7*]. An 8:1 scale model of a nuclear-reactor containment vessel with a design pressure of 40 psig (2.76 barg) was pneumatically pressurized to failure with nitrogen gas. The vessel failed at a pressure of 195 psig (13.4 barg). Figure 2 shows the locations of twelve resulting fragments, as indicated by Xs, and gives identification numbers for them. Fragment number 8 traveled 408 m (1,338 ft) from the original location of the test vessel. Baker [*7*] reports that the failure was ductile.

Range of projectiles from ductile fracture. HSE Guidance Note GS4 [*2*] gives the following equation for calculation of maximum fragment velocity for ductile fracture of a container:

$$v^2 = (2 \times d \times P_1 \times A)/m_f \qquad (5)$$

Where d is the diameter of hole left behind (Note: For small fragments such as plugs or small closures, it should be assumed that d is twice the diameter of the hole left behind); A is the area of ejected fragment; and m_f is the mass of the fragment.

Assuming an optimum projectile-launch angle of 45 deg, the maximum range of the fragment is then calculated with Equation (6):

$$R_{ductile} = v^2/g \quad \textbf{(6)}$$

These equations lead to projectile ranges similar in magnitude to brittle fracture, but the projectile ranges are highly dependent on the size and shape of the ejected fragment. For example, for a 100-barg test pressure leading to the failure of a 1.5-in., 600-lb nozzle, an exclusion zone of 22.4 m was calculated in a different study. That work was based on assuming that the nozzle fragment included [(Boss flange) + (0.3 m pipe) + (gate valve) + (flange) + (blind flange)].

Lighter fragments (for example, the blind flange) would fly farther. Table 1 presents values of $R_{ductile}$ calculated with Equation (6) for blind flanges. (Blind flanges were chosen to calculate $R_{ductile}$ because their size is well-defined for a given pipe class and size, and because they project a large area that is exposed to the escaping gaseous energy.) These distances are much larger than those in the different study cited above, and similar in magnitude to those calculated for brittle fracture using Equation (4).

Note that fragment ranges for small fragments can be significantly larger than those for blind flanges.

Probability of personnel injury by projectiles. Because of the potentially large ranges of projectiles from rupture of a piping system, the choice of exclusion zones for pneumatic testing could be quite large if they were based on these potential fragment ranges. However, most fragments from rupture of a piping system will fall near their original location (See Figures 1 and 2). One rough approximation proposed here regarding the distribution of fragments is to assume an exponential decay with distance.

Probability of a fragment at radius $r = e^{-2r/R}$ **(7)**

Where R is the characteristic range. Then, the probability of a fragment falling outside an exclusion zone (Z) becomes:

Probability of a fragment falling outside $Z = \int e^{-2r/R}\, d(2r/R)$ **(8a)**

And evaluating the integral between $2Z/R$ and infinity:

Probability of a fragment falling outside $Z = e^{-2Z/R}$ **(8b)**

If the exclusion zone (Z) is chosen to be equal to the characteristic range R (as calculated in Table 1 for the appropriate failure mode), then the probability of a fragment falling outside the exclusion zone is e^{-2} or 0.135 or 13.5%. The total number of fragments falling outside the exclusion zone would thus be 13.5% of the total number of fragments formed.

The problems in applying this concept to a quantitative estimation of the probability of a person being injured are: a) accurately estimating the number of fragments formed when a piping system ruptures; b) accurately estimating the characteristic range R; and c) accurately estimating the number of people in the area.

The probability of one injury during a pneumatic test at a facility depends on the probability of failure during the test, and the probability of injury during any single failure.

Probability of injury during a pneumatic test = (Probability of piping failure) × (Probability of injury outside exclusion zone, Z when pipe fails) × (Probability that a fragment falls outside Z) × (Number of fragments formed by failure) **(9)**

The Gas Research Institute sponsored a study of human and equipment failure rates in the LNG industry by Atallah, and others [8]. Its data include failure rates of piping systems. Applying data from plant operation to pneumatic testing prior to initiation of plant operation is questionable, but might be roughly indicative of the probability of a failure during test. Atallah,

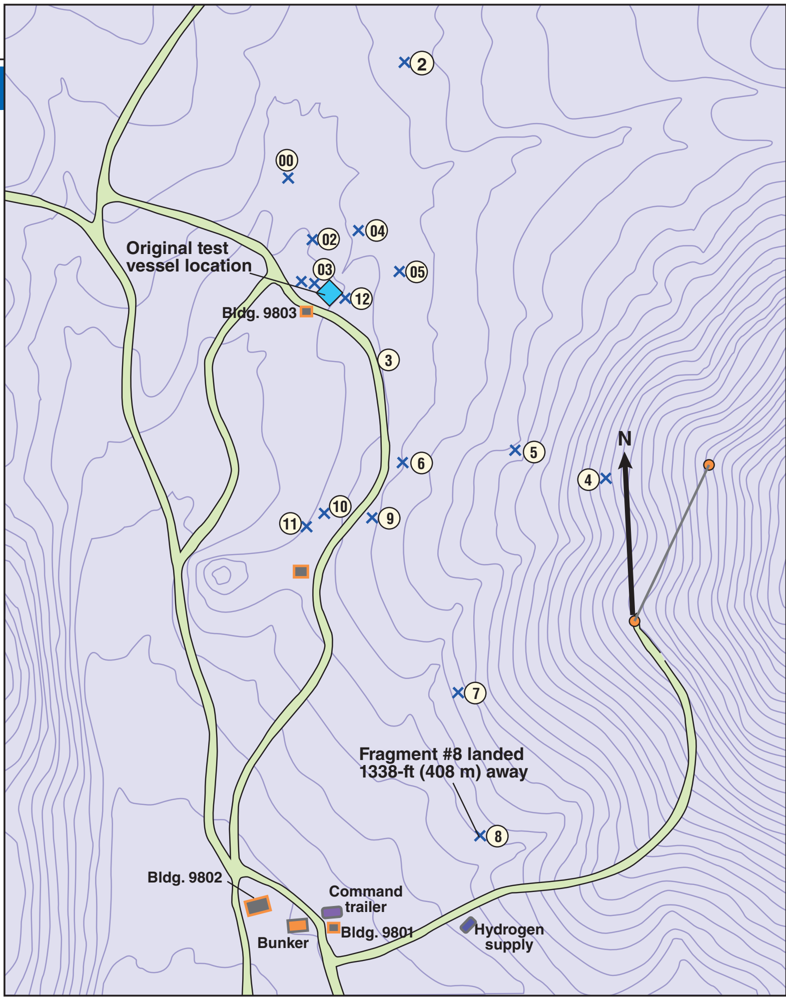


FIGURE 2. Missile map from test burst at 13.4 barg (195 psig) of steel vessel [7]

TABLE 3. TYPICAL FRAGMENT RANGES FOR BRITTLE FRACTURE BY METHOD OF BAKER [6]				
Fragment mass fraction	Fragment mass, kg	Exposed area, m^2	Velocity, m/s	Range, m
0.1	186	0.2027	109	1,093
0.2	372	0.2027	80.5	597
0.5 (2 of equal size)	930	0.2027	64.4	429
0.6	1,117	0.2027	63	419
0.7	1,303	0.2027	62.2	401
0.8	1,489	0.2027	61.8	399
0.9	1,675	0.2027	61.5	397

and others [8] presented a mean time between failure (MTBF) for LNG piping systems of 5.8×10^8 ft-hr.

Probability of one LNG piping system failure during pneumatic testing = [(Number of pneumatic test systems) ×(Length of pipe per system)× (Duration of each pneumatic test)]/ (MTBF) (**10**)

The test duration used in one project was approximately 2 h (1 h at lower pressures, 15 min at P_{design}, 30 min at P_{test}, and 15 min at P_{design}).

Assuming 200 LNG pneumatic-test systems and an average of 300 ft of pipe per test system, the probability of failure of one LNG piping system among all those tested during LNG pneumatic testing is approximately 1 in 5,000. Because of the "bathtub" shape of failure rate data, the probability of failure of an LNG piping system during test may be somewhat higher. (Graphs of failure rates versus time typically resemble a bathtub, with a high initial failure rate, then a constant and low failure rate during the expected life of the product, and finally an increasing failure rate at end-of-life.)

In the unlikely event of a failure of an LNG piping system during pneumatic pressure testing, all personnel would be protected from blast overpressure by the conservative exclusion zones in use. Although one or more fragments might fall outside the exclusion zone, most of the fragments would fall within the exclusion zone, and the probability of a person being struck by a fragment is very low.

A confidential and detailed quantitative risk assessment of a proposed pneumatic test of a 6-km LNG pipeline also yielded the conclusion that the risk of pneumatic testing would be acceptably low.

When rigorous precautions have been taken to establish safe testing procedures and to ensure the integrity of the piping systems being tested, the risk of pneumatic pressure testing of selected LNG piping systems can be made acceptable. As a minimum, rigorous attention needs to be given to the essential considerations listed in the box, Precautions in pneumatic pressure testing, p. 33.

Safe exclusion zones

The shock wave from rupture of a piping system under test could affect much of the immediate area surrounding the test, so the exclusion zone for the test should be at least large enough to keep the overpressure from exceeding the criterion selected in this article of 0.5 psig (0.0345 barg). The intent is that only those people conducting the pneumatic pressure test would be allowed to enter the exclusion zone and then only under carefully prescribed conditions.

Conversely, projectiles resulting from fragmentation of a piping system will be relatively few in number, and most would fall relatively close to their origin. The remaining few would be distributed over a comparatively large area and would have only a very low probability of hitting a person. These considerations form the basis of the logic of using only overpressure considerations in order to establish exclusion zones. ■

Edited by Dorothy Lozowski

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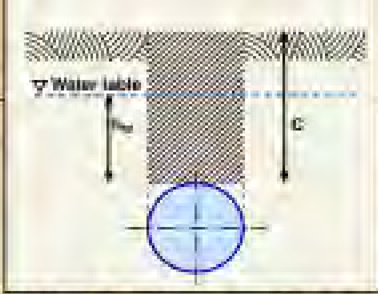

FIGURE 1. Soil pressure acting on pipe

Design UNDERGROUND PIPING For Safety

Subrata Saha
and
Sandip Vadher
Reliance Refinery

Buried systems bear a number of unique risks and require special considerations, including those related to soil characteristics and seismic loads

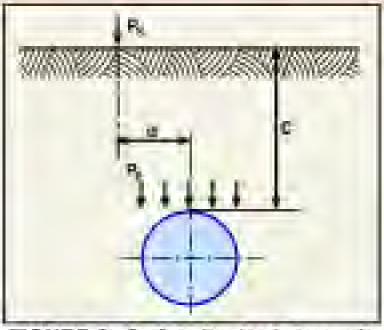

FIGURE 2. Surface live loads transmitted pressure on pipe

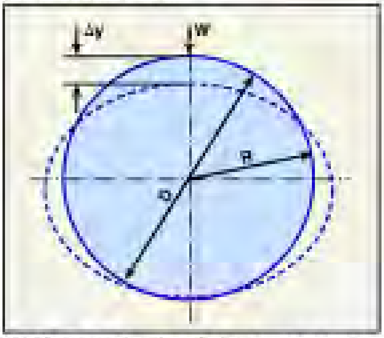

FIGURE 3. Ovality of pipe cross section

Buried piping — especially lines carrying hydrocarbons — shoulders many more risks in terms of plant safety and environmental protection than aboveground piping does. Leaks in buried pipes are much harder to detect and, yet, are no less catastrophic. Ironically, underground piping design does not get as much emphasis in the chemical process industries (CPI) as aboveground piping does. Whether the lack of attention is because many piping analysts consider underground piping design to require less skill or is due to some other reason, more attention is needed, with respect to critical design aspects. This article outlines the basics of buried, steel piping design, while Part 3 of the cover story (pp. 41–42) shares light on cost-effective methods of inspection that have been perfected in the upstream, petroleum oil-and-gas industry.

The critical design challenge that sets underground piping apart is that it must sustain other loads beside the internal fluid pressure. That is, it must support the soil overburden, groundwater, loads applied at the ground surface, such as vehicular traffic, and forces generated by seismic motion. Buried pipe is a structure as well as a conduit for conveying fluid. Therefore, special design procedures are required to insure that both functions are fulfilled. Stress analysis of underground piping is quite different from that of aboveground piping. Various factors such as soil to pipe interaction, dead and live loads of soil, anchorage force and so on, must be considered.

Basic design methodology

First of all, the applicable piping code has to be determined, and it depends on the area of application. For example, inside a process plant it could be ASME B31.3, or for gas transportation it could be B31.8. For a large network it could be a combination. The decision has to be reached in consultation with the plant representative and the engineering design team, and with the help of the project engineer. The applicable code will dictate the basic pipe thickness and the material of construction, depending on the process conditions.

The book by Moser [1] is an excellent reference and is a must read for understanding basic principles. As a design standard for buried piping, ASCE publication ALA [2] is widely popular and more or less comprehensive. Another important standard, API RP 1102 [3], is commonly followed for buried pipe design. It is mainly applied for railroad and highway crossings.

This article highlights the procedure as laid down in ALA and illustrates its use through a case study (pp. 39–40). There are essentially two aspects to acknowledge. One is the local analysis, and the other is a general thermal analysis. The local analysis determines the design adequacy against local deformations (including buckling) and against external loading. The thermal analysis is done in order to check against thermal overstress and is done per the governing code (for example, ASME B31.3 or B31.8). It should be noted that accurate soil data are mandatory for a proper analysis. This is because of the heterogeneous nature of the of the soil. Another important recommendation is to use data from a recent survey.

Determination of loads

The loads on the buried pipe are due to the following effects:

Overburden. Overburden is basically

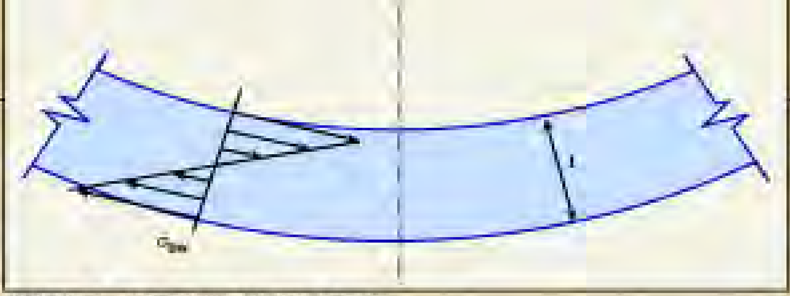

FIGURE 4. Through-wall bending stress

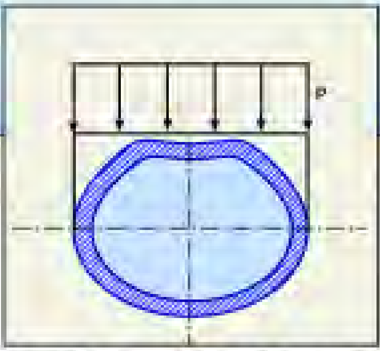

FIGURE 5. Ring buckling of pipe cross section

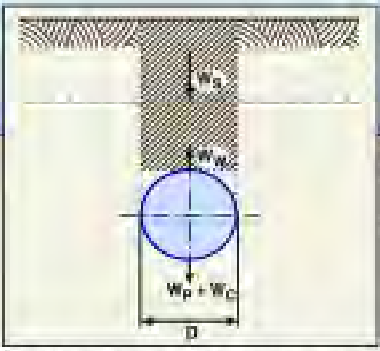

FIGURE 6. Resultant buoyancy load on pipe

the vertical earth load on the pipe (Figure 1). It consists of a block of soil (the soil prism) extending from the ground surface to the top of the pipe plus (or minus) shear forces along the edges of the block. The shear forces are developed when the soil prism above the pipe or the soil surrounding the prism settle relative to each other.

Vertical earth pressure on pipe can be calculated by Equation (1):

$$P_v = \gamma * C \tag{1}$$

Live loads. In addition to supporting dead loads imposed by earth cover, buried pipes can also be exposed to superimposed concentrated or distributed live loads (Figure 2). The main source of design live loads on buried pipes is wheeled traffic from highways trucks, railroad locomotives and aircraft. Live loads transmitted to the pipe can be estimated based on Boussinesq's equation [*1*] as follows:

$$P_p = \frac{3P_s}{2\pi C^2\left[1+\left(\frac{d}{C}\right)^2\right]^{2.5}} \tag{2}$$

Design check for overloads

After the basic loads are determined, the structural adequacy check should be carried out. The following sections describe the method for doing so.

Ovality check. A buried pipe tends to ovalize under the effect of surface earth and live loads (Figure 3). This is quantified in terms of the strain as follows in Equation (3):

$$\frac{\Delta y}{D} = \frac{D_l K P}{\frac{(EI)eq}{R^3} + 0.061E} \tag{3}$$

The pipe wall stiffness $(EI)_{eq}$ is the sum of the stiffnesses of the bare pipe, lining and coating.

$$(EI)_{eq} = EI + E_1 I_1 + E_c I_c \tag{4}$$

Where: $I = t^3/12$

The calculated strain is compared against the allowable strain, the value of which depends on the pipe material and may be obtained from the codes or design standards. For example, the allowable strain for carbon steel is 3%, per API RP-1102 [*3*].

Through-wall bending stress. As shown in Figure 4, through-wall bending stresses are induced in buried pipe due to surface earth and live loads. The stresses may be computed as follows in Equation (5):

$$\sigma_{bw} = 4E\left(\frac{\Delta y}{D}\right)\left(\frac{t}{D}\right) \tag{5}$$

Ring buckling critical load. Ring buckling refers to the local wrinkling as illustrated in Figure 5. Ring buckling could result in leakage and hence should be avoided.

Ring buckling critical load can be

NOMENCLATURE:

- A = Metal cross section area of pipe
- B' = Empirical coefficient of elastic support
- C = Depth of soil cover above pipe
- C_s = Apparent propagation velocity of seismic waves
- D = Pipe outside diameter
- D_l = Deflection lag factor (= 1.0–1.5)
- d = Offset distance from pipe to line of application of surface load
- E = Modulus of elasticity of pipe
- E' = Modulus of soil reaction
- F_b = Upward force due to buoyancy per unit length of pipe
- h_w = Distance between the top of pipe and the ground water table
- K = Bedding constant (= 0.1)
- L = Length of pipe span
- P = Pressure on pipe due to soil load plus live load
- P_p = Vertical pressure transmitted to pipe from live loads
- P_s = Concentrated load at ground surface
- P_v = Vertical soil trench pressure acting on the top of the pipe
- R = Pipe radius
- R_w = Water buoyancy factor
- t = Wall thickness of pipe
- T_u = Peak friction force at pipe, soil interface
- W = Weight of soil cover
- W_c = Weight of pipe content per unit length
- W_p = Weight of pipe per unit length
- W_w = Weight of water displaced by pipe
- Δy = Vertical deflection of pipe
- V_g = Peak ground velocity.
- Z = Elastic modulus of pipe cross section.
- γ = Density of soil
- γ_w = Unit weight of water
- γ_p = Density of pipe
- γ_f = Density of fluid
- ε_{ll} = Pipeline axial strain
- α = Factor applied to C_s in estimating ground strain from wave propagation
- λ = Wavelength
- σ_{by} = Stress calculated by buoyancy
- σ_{bw} = Through-wall bending stress
- P_{cb} = Ring buckling load
- σ_y = Specified minimum yield stress (SMYS) of pipe
- μ = Coefficient of friction
- Φ = Friction angle

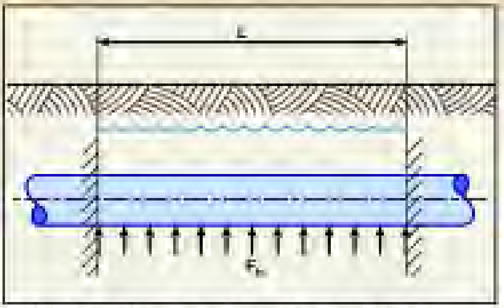

FIGURE 7. Distributed buoyancy load on pipe

FIGURE 8. Weight distribution on a buried pipe

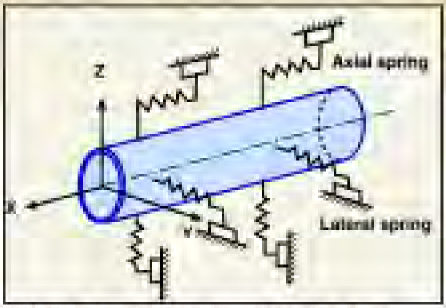

FIGURE 9. Idealized representation of soil with discrete springs

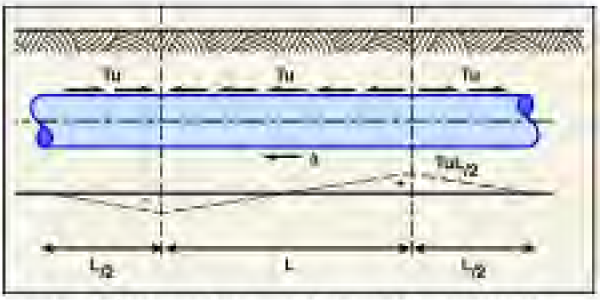

FIGURE 10. Ground movement (labeled Δ) and zones of pipe axial tension and compression for longitudinal PGD

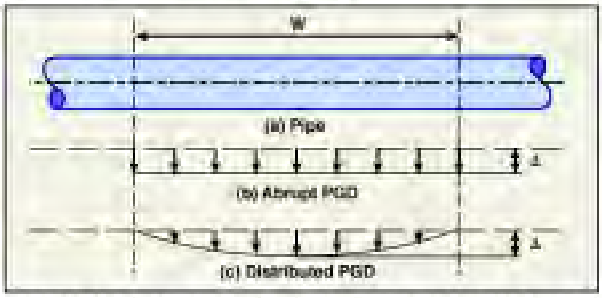

FIGURE 11. Transverse PGD with spatial extend (W) and amount of movement (labeled Δ)

evaluated as follows:

$$P_{th} = \frac{1}{FS}\sqrt{32R_w B' E' \frac{(EI)_{eq}}{D^3}} \quad (6)$$

Where,

FS = Factor of safety
= 2.5 for $(C/D) \geq 2$
= 3.0 for $(C/D) \leq 2$
$0 < h_w < C$

$$R_w = 1 - 0.33\left(\frac{h_w}{C}\right),\ 0 < h_w < C \quad (7)$$

$$B' = \frac{1}{1 + 4e^{\left(-0.065\frac{C}{D}\right)}} \quad (8)$$

Uplift force (buoyancy) check

Net upward force occurs on buried pipe when the buoyancy force created by the pipe below the water table exceeds the combined downward weight of the pipe and soil column above the pipe (Figure 6).

In order to calculate the largest upward force, we have to assume the buried pipe to be empty during testing and installation periods. The upward force imposed on buried steel pipe below the water table (Figure 7) is:

$$F_b = W_w - \left[W_p + W_c + \left(P_v - \gamma_w h_w\right)D\right] \quad (9)$$

If the pipe is below the water table, earth pressure can be calculated as

$$P_v = \gamma_w h_w + R_w \gamma C \quad (10)$$

Where weight of pipe content per unit length (W_c) is equal to zero.

The longitudinal stress induced in the pipe by buoyancy forces can be calculated by Equation (11):

$$\sigma_{bf} = \frac{F_b L^2}{10Z} \quad (11)$$

Thermal expansion stress

For any temperature variation (rise or fall) there is a stiff resistance from the soil. Soil-to-pipe interaction analysis is the most important part of buried-pipe line-stress analysis. This is in sharp contrast to aboveground piping, which normally has free growth except at restraints. For buried pipes, friction force is the first force that affects pipe movement and acts against the axial pipe movement. Theoretically, friction force is equal to the product of friction coefficient and the total normal force acting all around the pipe. Figure 8 shows the force distribution.

The expression for the friction force [4] is the following:

$$f_{sc} = \mu\left(W + W + Wp + Wc\right) = \mu\left[2\gamma DC + \pi D r \gamma_p + \left(\frac{\pi}{4}\right) D^2 \gamma_f\right] \quad (12)$$

Lateral soil force acts when pipe moves horizontally. A passive soil pressure is created at the front surface and at the same time receives an active soil pressure at the back. If the active pressure is ignored, the only lateral force is the passive force [4], which can be written as follows:

$$f_{lr} = 0.5\gamma\left(C + D\right)^2 \tan^2\left(45 + \frac{\phi}{2}\right) \quad (13)$$

In ideal conditions, soil acts as springs (Figure 9). Lateral force can be divided into two stages: an elastic stage, where resistance force is proportional to pipe displacement and a plastic stage, where resistance remains constant regardless of displacement.

Soil stiffness can be calculated as dividing forces [defined by Equations (12) and (13)] by yield displacement

CASE STUDY

We consider the design of a portion of a buried pipe carrying fuel gas as shown in Figure 12 (all dimensions are in mm). There is a road crossing, but not a highway or a railroad crossing. In order to limit the thermal expansion, anchor blocks have been provided. The soil properties and the other input design parameters are given in Table 1. The site is in a seismically active zone and hence seismic design check must be carried out. However no seismic faults are postulated.

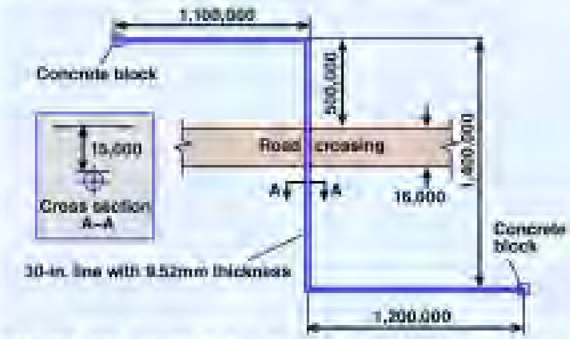

FIGURE 12. Typical layout of underground hydrocarbon line

TABLE 1. INPUT DESIGN PARAMETERS	
Line data	
Diameter of pipe (D)	30 in.
Pipe material	A671CB6013
Pipe thickness (t)	9.52 mm
Design temp	65°C
Ambient temp	21°C
Design pressure	42 kg/cm^2
Fluid density (γ_f)	26.1 kg/m^3
Soil data	
Soil density (γ)	2,140.67 kg/m^3
Modulus of soil reaction (E')	2.757 MPa
Friction angle (Φ)	33 deg
Friction coefficient with pipe	0.5
Depth of buried pipe (C)	1,500 mm
Deflection lag factor (D_L)	1.5
Bedding factor (K)	0.1
Seismic data	
Peak ground velocity (V_g)	180 mm/s
Apparent propagation velocity (C_s)	3,750 m/s

Discussion

The design code was first decided. The choice was between ASME B31.3 (process piping) and B31.8 (gas transmission piping). As the portion within our scope was within the plant, design code B31.3 was adopted. However the line is a cross-country pipeline, and outside the premise of the plant the applicable code is B31.8. But the work scope was of a different part.

Using data from Table 1, the loads were calculated per the relevant equations, and the results are presented in Table 2. For the surface loads, the values were obtained from the maximum possible vehicular load at the crossing. There is a possibility of water logging, and hence, the buoyancy force was also calculated. It was found to be insufficient to cause upheaval, and hence, not of concern.

(Continues on p. 40)

(Y_d), as defined in Equation (14).

$$Y_d = 0.015\,(C+D) \tag{14}$$

Hence, axial stiffness (K_{ax}) on a per length of pipe basis is as follows:

$$K_{ax} = f_{ax} / Y_d \tag{15}$$

Lateral or transverse stiffness (K_{tr}) on a per length of pipe basis is as follows:

$$K_{tr} = f_{tr} / Y_d \tag{16}$$

Further details may be obtained from the paper by Peng [4].

Seismic stress check

Underground and aboveground seismic design philosophy. Although the basic source of excitation is the ground motion, its effect on the aboveground and underground piping is quite different. The vibratory motion of the pipe supports induces inertial response in the aboveground piping. The inertial force induces seismic stresses in the piping components. The stresses are combined with the operating stresses and checked against the allowable stresses per the applicable codes.

Since buried pipes are encapsulated in the soil, the ground displacement is the prime factor, and hence, its design is based on strain rather than stress. The pipe strain induced by the seismic ground motion is the governing parameter. This strain is to be limited within the permissible values. The limiting values will depend on the pipe material and also the type of joints. For segmented pipe lines (consisting of pipe segments connected by flexible connections, such as bell spigot joints) the joint rotation and joint displacement are the governing parameters.

Various seismic damage modes. There are primarily three types of damage in buried pipes due to seismic activation. These damages are due to ground shaking or wave propagation, ground deformation due to soil failure and ground deformation due to faulting. A combination of all the three could occur during a seismic event. Ground shaking refers to the transient soil deformation. It is often characterized in terms of peak ground velocity (PGV) or acceleration (PGA) [5, 6]. Figure 10 shows that permanent ground deformation (PGD) is another major source of hazard. PGDs are non-recoverable soil movements due to landslide surface faulting or liquefaction induced spreading. There could be axial, transverse as well as flexural deformations of the pipe (Figure 11). It is found that longitudinal PGD is of greater importance as far as pipeline failure is concerned [5, 6]. Liquefaction generally occurs in loose, saturated, granular soils when subjected to strong ground shaking for long durations and causes a spread in the PGD. However, for simplicity we will limit ourselves here to ground shaking effects only.

Ground shaking is associated with wave transmission. Wave propagation provisions are presented in terms of longitudinal axial strain, that is strain parallel to the pipe axis induced by ground strain. The axial strain induced in a buried pipe by wave propagation can be calculated as follows:

$$\varepsilon_a = \frac{V_g}{\alpha C_s} \tag{17}$$

The axial strains produced by Equation (17) can be assumed to be transferred to the pipeline but need not be taken as larger than the axial strain induced by friction at the soil pipe interface:

$$\varepsilon_a \le \frac{T_u \lambda}{4AE} \tag{18}$$

CASE STUDY

(Continued from p. 39)

The calculated design parameters are shown in Table 3. It is seen that there is some overshooting of the parameters (for instance, through-wall bending stress). This was at the road crossing. To overcome it locally, thickness of the pipe could be increased, or a stronger material could be used. But in this case, the thermal stress at the elbows would increase. In fact, the end-anchor points have been designed to limit the thermal stresses. Finally, an encasing on the pipe was provided at the road crossing in line with API RP 1102.

TABLE 2. LOADING CALCULATIONS

	Formula	Load on pipe	Remarks
Vertical earth load	$P_v = \gamma * C$	0.032 MPa	If line is above water table
Vertical earth load	$P_v = \gamma_w h_w + R_w \gamma C$	0.036 MPa	If line is below water table
Water buoyancy factor	$R_w = 1 - 0.33\left(\frac{h_w}{C}\right)$	0.67	Considering $h_w = C$
Surface live loads	$P_p = \frac{3P_s}{2\pi C^2\left[1+\left(\frac{d}{C}\right)^2\right]^{2.5}}$	0.034 MPa	
Total load	$P = P_v + P_D$	0.065 MPa	
Ring buckling load	$P_{rb} = \frac{1}{FS}\sqrt{32R_w B'E'\frac{(EI)_{eq}}{D^3}}$	0.22 MPa	$P < P_{rb}$
Buoyancy force	$F_b = W_w - \left[W_p + W_c + \left(P_v - \gamma_w h_w\right)D\right]$	-13.35 N/mm	Buoyancy not affecting design

TABLE 3. CALCULATED PARAMETERS FOR DESIGN CHECK

	Formula	Stress/ strain	Allowable	Remarks
Ovality check	$\frac{\Delta y}{D} = \frac{D_l KP}{\frac{(EI)eq}{R^3} + 0.061E}$	2.2%	3%	Pass
Through-wall bending stress	$\sigma_{bw} = 4E\left(\frac{\Delta y}{D}\right)\left(\frac{t}{D}\right)$	227.88 MPa	σy	Failure at road crossing
Buoyancy stress	$\sigma_{bf} = \frac{F_b L^2}{10Z}$	0	σy	Not applicable
Seismic stress	$\varepsilon_s \frac{V_s}{\alpha C_s}$	24 E-06	0.5 %	Pass
Thermal stress		95 MPa	226 MPa	Pass

Final thoughts

Through the case study we have explained the basic concepts in the design of underground pipes. Also an approach to the design has been provided. As delineated above, the first step in designing underground piping for safety is to select the appropriate codes and standards. This is essentially a key factor as the entire design and material selection will depend on it. But, most important of all, a large number of soil parameters have to be accurately known. This is difficult due to the heterogeneous nature of soil, which is site specific. Survey and determination of soil properties by testing is preferred. Unlike aboveground analysis the underground analysis consists of both local as well as the conventional thermal analysis with soil springs. But, it may be noted that a small temperature change could be detrimental for the buried piping components, which otherwise is not a concern for aboveground piping. Another distinguishing feature is the seismic analysis of buried piping, which is based on a quite different principle. In a way it may be seen that the underground piping analysis requires some specialty expertise. But once the basic principles are understood it is not difficult to carry out a reliable design. ■

Edited by Rebekkah Marshall

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Inspecting UNDERGROUND PIPING

First consider noninvasive methods to determine where excavation is — and isn't — necessary

Brant Shields
PetroChem Inspection Services, Inc.

Piping integrity is always a major concern in the chemical process industries (CPI), but the level of concern elevates when piping is buried underground. Soil conditions not only exacerbate general external corrosion, but also increase the difficulty and cost of inspection — a necessary step for ensuring safe and reliable operation. Making matters worse, many underground piping systems are incompatible with so-called pipeline pigs, designed in short lengths and come in the most undesirable configurations known to man. (For more on design considerations for underground piping, see Part 2 of this report, pp. 36–40).

While removing a line from service to perform an inline inspection or hydrotest is common and feasible with aboveground piping, it does not prove sustainable or cost effective for underground piping. The necessary time and costs for excavation are simply too great (Figure 1 and 2). Fortunately, advancements in technology have led to numerous methods that help minimize the amount of excavation that is necessary, but their use is not well known in the CPI. While the full description of these technologies is beyond the scope of this article, this brief synopsis sheds light on the methods and tools that are appropriate and available for CPI use.

Initial considerations

In order to prevent catastrophic failures or unplanned downtime, an assessment program and a sound inspection plan are the key steps. Within this program, the proper inspection technique can facilitate the location, examination and quantification of damage mechanisms, such as internal and external corrosion, cracking, third-party damage and manufacturing flaws, so the appropriate intervention or remediation can be taken.

During inspection implementation, numerous details must be taken into consideration, such as location, size, length to be tested, accessibility, existence of cathodic protection (CP) and the potential for corrosion, to mention a few.

Minimize excavation

The primary costs when evaluating buried piping is attributed to the time spent on preparing excavations to access questionable piping. So, achieving accurate and repeatable data is vital for minimizing the amount of excavations and minimizing costs.

Direct assessment. The form of inspection known as DA (direct assessment) was originally developed for natural-gas transmission pipelines to detect and analyze different types of integrity threats in non-piggable pipelines. By using several of these applications, such as external corrosion direct assessment (ECDA) and internal corrosion direct assessment (ICDA), end users can first identify areas of probable concern and high consequence within the facility before embarking on excavation. ECDA uses location, soil conditions, coating conditions, CP and so on, to determine the potential for external corrosion. ICDA analyzes product, pressure, flow and other parameters to determine the potential for internal corrosion. Beginning with the platform of pre-assessment, followed by indirect or direct inspection practices and post assessment, the integration of the data acquired by both ECDA and ICDA can help develop a maintenance and inspection program for future monitoring.

FIGURE 1 and 2. The primary cost of evaluating buried piping is attributed to the time spent on preparing excavations to access questionable piping

Indirect inspection. Aboveground methods such as close interval potential survey (CIPS), direct-current voltage gradient (DCVG) and alternating-current voltage gradient (ACVG) are all indirect methods of inspecting buried piping from above grade for the identification of active corrosion or coating faults. CIPS examines the pipe-to-soil potential. Cathodic protected piping propagates a current that flows through the soil onto the pipeline, measuring the level of this current and noting the contact interface changes that can determine the level of protection being provided by the system. DCVG and ACVG, in comparison to each other, are similar types of surveys. The foremost difference between the two inspection methods is the power source that sends current to the pipeline for measurement. Both systems measure the voltage gradient along the buried segment. The gradient measurements are generally viewed as "the larger the voltage gradient, the larger the coating defect". These methods can locate areas of concern for subsequent excavation and verification using other complementary techniques.

Direct inspection. Direct inspection methods have been proven for numerous years and often only require a small area of excavation. Guided wave ultrasonics, for example, only require 4–8 ft of exposed pipe for inspection. In general, guided wave ultrasonics provide a way to inspect lengths of piping from a single test position by generating low frequency guided waves and transmitting these down the length of the piping. Within this diagnostic test length, 100% of the circumference is inspected. Although both internal and external metal losses are detected, this method cannot distinguish between the two. Systems use a pulse echo operation that provides the inspector with the ability to quickly identify problem areas and metal loss. Sensitivity of guided waves typically is in the range of 4 to 6% loss of cross section, but this greatly varies pending the condition of the system being evaluated.

When using guided wave ultrasonics on buried piping segments, many variables, such as coating and soil conditions, can affect the results. Considering the fact that most buried piping systems are coated with some type of coal tar, fusion bonded epoxy (FBE) or bitumen wrap, excessive testing lengths (> 15m) are not practical, and shorter lengths with limited access are ideal. Using this method as a screening tool, which is the intended use by manufacturers, the end user can obtain quantitative views of the segment tested and qualify the findings with other non-destructive examination (NDE) methods. The use of this application is considered an advanced technique, and only technicians with a high level of training and experience should be used for such applications.

Another direct inspection method, automated ultrasonic testing (AUT), is a qualitative method for obtaining exact wall thickness measurements on piping in the areas of pitting or general corrosion. With numerous systems and users within the industry, this technology uses digitally controlled ultrasonic scanners for data acquisition and specialized software for data processing and display. The use of automated systems is driven to ensure complete coverage of the test specimen with greater accuracy. The scanners often used are either raster type or encoded linear scanners, all automated and programmed for a particular grid span or coverage plot, designed to eliminate human error. Depending on which system is applied, different ultrasonic displays can be given; the basic displays in AUT will typically include A-Scan, B-Scan and C-scan.

FIGURE 3. Direct methods such as guided wave ultrasonics can inspect lengths of piping from a single test point

Automated ultrasonics can be used as part of the overall process for determining mechanical integrity. Accuracy of the systems varies, most are in the range of ±0.003–0.010-in. variance in thickness calibration, which provides very accurate data for service calculations. In most cases, the areas to be tested should be reasonably clean of any coating, with the external condition of the piping smooth with minimal external corrosion. This application is ideal for verifying anomalies discovered by use of other quantitative methods, such as guided wave inspection.

There are many different types of cracking found in the various industries; one of the more prevalent is stress-corrosion cracking. Various environmental conditions can attribute to cracking from temperature and soil conditions to pressure and stresses. Locating potential areas based on ideal conditions for environmental cracking and validating the existence and sizes are an important part of inspecting buried piping. Alternating-current field measurement (ACFM) provides a method for crack detection and sizing. The technology uses an alternating current field, which flows on the surface of the material being tested. When a surface breaking crack is present, the field is disturbed, thus revealing the crack location. Special techniques are used to induce these currents, which allow the disturbances to be measured and quantified in multiple dimensions. The use of these data eliminates unnecessary grinding out of indications and can provide accurate sizing information for integrity assessments. ACFM can be performed through most coatings with minimal surface preparation.

There is no one tool that can provide all the necessary data required when inspecting buried plant piping. Complementary techniques form a comprehensive testing strategy for discovering what lies beneath. ■

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Managing Compliant MSDSs and Labels

Compliant MSDS programs depend on inventory management, regulatory knowledge and consistent authoring

Jytte Syska and Tamie Webber
3E Company

FIGURE 1. The advent of GHS and REACH regulations brings new challenges to the already demanding and mission-critical task of authoring compliant MSDSs

Chemical regulatory compliance is growing in complexity as product sourcing and formulations proliferate and organizations expand into new markets on a global scale. Staying current with the requirements of international regulatory initiatives such as the Globally Harmonized System of Classification and Labeling of Chemicals (GHS) and the Registration, Evaluation and Authorization of Chemicals (REACH) adds to the challenge (*CE*, March 15, 2008, p. 38–47, and *CE*, June 15, 2008, p. 26–30).

A key compliance requirement of these initiatives is the proper management of Material Safety Data Sheets (MSDSs) and labels. Both GHS and REACH significantly impact the corporate strategy for MSDS management, as the regulations require affected companies to update these documents to maintain compliance. Comprehensive inventory management, thorough regulatory reporting and consistent MSDS and label authoring are three critical components of a REACH- and GHS-compliant MSDS management program.

MSDS management

Accurate chemical inventory management is the cornerstone of any MSDS management program. Regulatory compliance mandates that companies obtain and maintain MSDSs for the raw materials, as well as for the full composition of mixtures. For REACH compliance, this requirement helps companies establish the category into which individual substances fall: manufactured within the European Union (E.U.), imported into the E.U., or purchased from a supplier within the E.U. For REACH, companies also must identify each substance's tonnage and current classification.

Comprehensive regulatory reporting is also crucial to achieving GHS compliance. In addition to consistently tracking regulations, companies must track modifications made to ingredients, products, and quantities and inventories.

While authoring accurate and compliant MSDSs has always been a mission-critical obligation, the advent of REACH and GHS brings new challenges to this already highly demanding task. For higher-volume hazardous substances, REACH requires companies to attach an exposure scenario to the MSDS. The exposure scenario describes how the chemical can be used in a safe manner, with minimal risk, for the intended use. The exposure scenario can cover either each individual substance in the chemical product or describe the mixture as a whole.

The first registration deadline under REACH passed on December 1, 2010. Import or manufacture of high-volume chemical substances and of CMR- (carcinogenic, mutagenic and toxic-to-reproduction) classified substances is no longer possible unless the importer or manufacturer has registered under REACH. Many of the substances that were registered for the December 1, 2010 deadline have exposure scenarios. The registrant must attach the appropriate exposure scenarios to their MSDSs, and the company using these substances must then include the information from the exposure scenarios when they prepare and supply the MSDSs to their customers. The European Chemical Agency (ECHA) has recommended a four-section exposure-scenario format, but many different formats are being used. Work is ongoing to harmonize the information in the exposure scenarios and to establish a common XML format for data exchange.

As a step toward improved compliance, companies should obtain the necessary overview of the current regulations and detailed understanding of how they relate to their chemicals and their supply chain. Manufacturers, users and distributors should be aware not only of their own obligations but also of those to downstream customers and to employees. In addition, corporate product-stewardship staff must understand when these regulations are implemented by country in order to know how to properly plan.

GHS

GHS is the United Nations (UN) system for harmonization of classification and labeling of chemicals. GHS has already been officially adopted by certain countries in regions around the globe. Countries can choose to implement GHS in its entirety or implement only certain parts of the regulation, otherwise known as the "building block" approach.

The true complexity of the standard is realized when reviewing its implementation status in a sample of countries around the world. For representative comparison purposes, we have provided a brief overview of the status of GHS in the following areas: the U.S., Japan and the E.U.

The U.S. On September 30, 2009, the U.S. Occupational Safety and Health Admin. (OSHA; Washington, D.C.; www.osha.gov) released its proposal to modify the current Hazard Communication Standard (HCS) to conform with the GHS.

The proposed OSHA revisions include both philosophical and tactical changes to hazard communications, which have far-reaching implications for MSDSs and the authoring, publishing, distribution and management of labels. The proposal also includes revised criteria for the classification of hazardous chemicals, as well as changes to definitions and terms used in the standards, and new training requirements for employees. When the final rule is promulgated, companies will face many challenges, including re-evaluating how their substances and mixtures are classified, re-issuing MSDSs and labels, and training staff as appropriate.

FIGURE 2. Service providers can help companies stay ahead of the regulatory compliance curve

After having accepted public comments until the end of 2009, OSHA has estimated that a minimum of 18 months will pass from the notice of proposed rulemaking before the final rule is promulgated. Companies will have three years from promulgation to come into compliance with the final rule and two years to implement training requirements on the final regulation. Once the rule is final, companies can begin implementation. However, in accordance with a letter of interpretation from OSHA on October 6, 2009, companies can begin following the E.U. GHS-label format for their OSHA labels as long as the labels also comply with the current HCS.

In addition, 26 U.S. states and territories have their own OSHA-approved plans. The 26 are: Alaska, Arizona, California, Connecticut, Hawaii, Indiana, Iowa, Kentucky, Maryland, Michigan, Minnesota, Nevada, New Jersey, New York, New Mexico, North Carolina, Oregon, Puerto Rico, South Carolina, Tennessee, Utah, Vermont, Virginia, Virgin Islands, Washington, Wyoming. They will have six months from promulgation to adopt comparable provisions of the final standard. In the meantime, each individual state plan will remain in effect until it adopts the required revisions.

Provided the legal process proceeds as planned, companies would be allowed to issue MSDSs and labels for the U.S. market according to the changed rule, based on GHS classification, no earlier than July 2011, and all existing MSDSs and labels would have to be updated in accordance with the new requirements no later than July 2014. In comparison, MSDSs for the European market had to be in line with the E.U. GHS implementation no later than December 2010 for pure substances and by June 2015 for chemical mixtures.

The label requirements will involve changes in the printing process and most likely will require many companies to invest in new label printers. Labels on products that are shipped outside the U.S. must have the chemical hazard pictograms with a red frame, signal words and the required hazard and precautionary statements. It is still being determined whether or not empty frames will be accepted on the label and whether or not labels for products sold and used exclusively in the U.S. can have the frame printed in black.

Japan. In Japan, the Industrial Safety & Health Law (ISHL; December 2006) currently details requirements for MSDSs and labels. The ISHL provides a list of substances that are subject to MSDS and label requirements, and also provides a classification results list, which details the classification of about 1,500 regulated chemicals. The Japanese Industrial Standard (JIS), which specifies the standards used for industrial activities in Japan, also has requirements for labels (JIS Z 7251:2006) and MSDSs (JIS Z 7250:2005). Recently JIS Z 7252:2009 was published for the standard of GHS classifications for health and environmental hazards.

E.U. The European Union is currently in a transitional period with regard to GHS. The European Parliament finalized and issued the Regulation (EC No. 1272/2008 on classification, labeling and packaging of substances and mixtures — the CLP Regulation) in late 2008. An amendment bringing the CLP in line with the third revision of the GHS was drafted in 2010.

The CLP Regulation provides the following transitional periods for classifying and labeling hazardous substances and mixtures:

- Substances must be classified, labeled and packaged according to CLP from December 1, 2010 forward
- Mixtures can be classified, labeled and packaged according to the Preparations Directive until June 1, 2015
- Supplemental labeling information, in line with the old labeling system's requirements, is still applicable under the CLP

The transitional periods for re-labeling and re-packaging of substances and mixtures placed in the supply chain before December 1, 2010 are postponed until December 1, 2012 and June 1, 2017 respectively.

REACH

The E.U.'s REACH regulation went into effect on June 1, 2007 — sometimes simplifying, but also complicating, the compliance work for companies manufacturing in, importing into or exporting from European countries. As a result of the new legislation, all companies manufacturing, importing, distributing or using chemical substances (on their own, in mixtures or in articles) in Europe, are required to closely examine their chemical inventory for substances within the scope of the regulation to ensure compliance.

Key components of REACH mandate the following:

- Registration of manufactured/imported chemical substances
- Increased information and communication throughout the entire supply chain
- Evaluation of some registered substances
- Authorization for use of substances of very high concern
- Restriction of the use of certain substances for specific applications

The scope of REACH is vast, and there are several issues that could impact a company's ability to meet its obligations under REACH, including changes to the content of MSDSs. Under REACH, additional information from manufacturers is required and the information must be aligned with that associated with the registration of the substance. When an exposure scenario has been required as part of the REACH registration of a substance, every safety data sheet for a product containing this substance must have the exposure scenario attached.

Choosing the right tools

As many companies realize, establishing GHS and REACH compliance is difficult. However, there are service providers who can help companies stay ahead of the curve with solutions for identifying and managing the increasingly complex and changing global chemical-regulatory obligations associated with GHS and REACH. These vendors can help address the new requirements and associated chemical regulatory information needed for compliance management as they arise.

For example, there are several commercially available content tools that can be used to feed chemical regulatory data into corporate EH&S (environmental, health and safety) and MSDS authoring systems. These integrated data tools provide efficient change management and regular updates as regulations change and new ones are released. These tools can help ensure correct, consistent GHS classification and labeling according to the U.N. purple book and also take into consideration the national deviations and other national regulations. Document templates for producing MSDS, labels and other hazard communication documents and multilingual phrase libraries can complete the content suite for efficient production of accurate documents.

Companies also may choose to employ outsourced services for their GHS classification of substances and mixtures as a separate service or as part of outsourcing MSDS and label authoring.

In-house MSDS authoring staff may want to adopt an authoring platform that will help generate hazard communication documents to meet GHS-related, international-regulatory compliance and business requirements. Such a platform should provide full support of hazard communication, classification and labeling requirements to generate globally compliant MSDS and label documents as well as business- or user-definable documents, such as technical data sheets, product data sheets, hazard summaries and product stewardship summaries. The system should use algorithms to accommodate the requirements outlined in the GHS. This consists of the classification of substances and mixtures according to their health, environmental and physical hazards and hazardous communication requirements for labeling and MSDS.

For inbound vendor MSDS management, users will want to search, print, view and Email vendor and raw material safety data sheets in a company-specific database via a Web-browser interface. As GHS requirements increase the burden of vendor MSDS management, a robust MSDS management system can help reduce the time and resources necessary for effective compliance management.

Compliance help is available

Creating, analyzing and managing globally compliant MSDSs, product label content and hazardous materials transportation documents that reflect both GHS and REACH requirements can be extremely challenging. Strong processes, applications, systems and service providers are needed to support the various aspects of compliance management. Companies that are impacted by GHS or REACH, or both, can seek assistance from providers who are well versed in data and other content and information as they relate to global EHS regulations and who thoroughly understand the global regulatory environment. These providers will be able to assist in implementing GHS and REACH compliance activities into the organization, and can help facilitate compliance with these increasingly complex and changing global, chemical regulatory obligations. ■

Edited by Scott Jenkins

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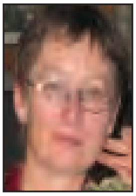

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OWNERS AND CONTRACTORS: Key Metrics Improve Performance

The selection and use of the right key performance indicators during capital-intensive projects can benefit all stakeholders

Cosimo Cannalire, Technip Italy S.p.A.

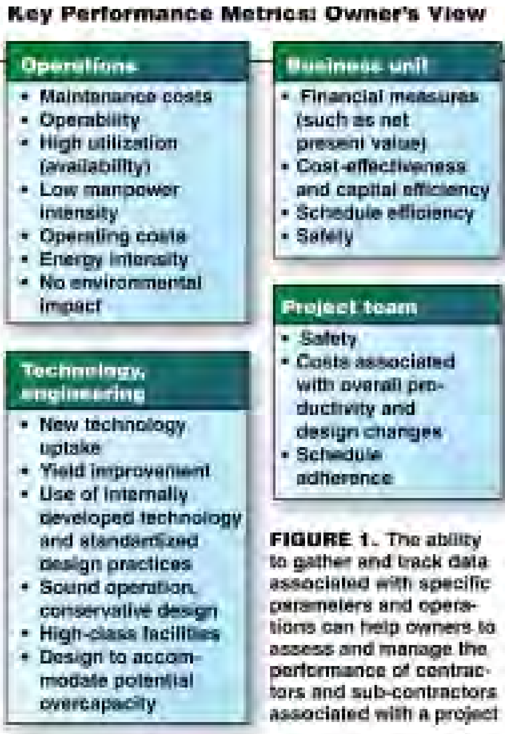

FIGURE 1. The ability to gather and track data associated with specific parameters and operations can help owners to assess and manage the performance of contractors and sub-contractors associated with a project

Throughout the chemical process industries (CPI), project owners often track key performance indicators (KPIs) to ensure that all participants are able to attain or improve important performance objectives associated with their investments. For instance, for complex projects involving various contractors and sub-contractors, the predetermined expectations spelled out in the agreed-upon set of KPIs allow all stakeholders to track and verify progress, stay informed throughout the process, and take any necessary actions or adjust their communications, as needed.

And, by developing incentives and penalties that are tied to specific KPIs, owners are able to measure, and in some cases reward achievements attained by a given contractor during both the front-end loading (FEL) and execution of the project. Such an approach is based on benchmarking against predefined parameters that are typically articulated as a set of contractual incentives.

This article addresses the rules for establishing which types of incentives should be used in each project stage, and discusses some of the advantages and disadvantages of the parameters presented.

Incentives

When owners track KPIs to measure the success of any capital-intensive initiative they fund, the goal is to identify and pursue changes that may be needed to attain their objectives. Figure 1 shows some of the KPIs that are most widely used by CPI project owners.

Similarly, contractors can and should use KPIs to track the progress of any project work they undertake and measure the success of what they design, procure and build. As shown in Figure 2, the KPIs that are important to contractors typically involve a mix of internal and external performance objectives. External KPIs are those that are to be shared with project owners.

The selection of the most useful and appropriate KPIs for any project must reflect the shared expectations of all stakeholders. In general, all parties should propose and agree on selected performance parameters that will help all participants to achieve the following:

- Meet respective business objectives
- Ensure a reasonable profit for both sides that is commensurate with the performance and the value created

The chosen metrics must also be:

- Transparent to both parties (embracing an "open-book estimate" approach and behavior)
- Realistic, so as to discourage "gaming" and instead encouraging open communication (here the goal is to avoid unrealistically stretched targets on the owner's side and hidden cost overruns on the contractor's side)
- Outwardly focused (they should be clear and easy to "sell" to the project stakeholders)
- Productive and mutually beneficial to both owner and contractor

Figure 3 shows some additional features that should be considered when deciding which are the most appropriate KPIs to track for a given project. As noted, it is important that the particular suite of selected metrics for any given project reflect a spirit of partnership and alignment among the parties. Once jointly selected, the chosen KPIs are then typically articulated as specific contractual incentives.

In general, project incentives should be self-funded to the greatest extent possible — that is, they should not represent an additional burden for the project's budgeted cost. This goal is often achieved by means of funding incentives through the potential savings that may be achieved by not using the targeted cost-contingency embedded in the budgeted value (this is discussed in greater detail below).

Generally speaking, the incentive program should be designed to obtain the full commitment of all parties. This will help to ensure the overall project success. Such a spirit of committed teamwork can help to achieve a safe and flawless plant startup, and

Key Performance Metrics: Contractor's View

External (typically developed in conjunction with the project owner)

- Safety
- Costs associated with productivity and design changes
- Schedule
- Responsiveness

Internal:

- Productivity – work hours/units (home office, field)
- Rework
- Client factor and impact on productivity
- Management of change
- Client satisfaction
- Industry benchmarks
- Reasonable profit

FIGURE 2. Contractors involved in capital-intensive projects should identify, develop and track relevant KPIs related to these work aspects. Typically, a mix of internal and external performance metrics are used

Shared Metrics' Rules-of-thumb

In general, as project-specific KPIs are selected, they should:

- Represent neither a 'carrot' nor a 'stick,' but a shared goal
- Involve shared responsibility among all stakeholders
- Recognize differences in the business drivers of both owners and contractors, being complementary but not conflicting
- Attempt to achieve a fair balance of partners' needs
- Be flexible (when it comes to project type, region, and so forth)
- Be ambitious but set goals that are achievable and motivating
- Seek to achieve a balanced outcome
- Represent realistic characteristics of the project

FIGURE 3. Follow these general guidelines when selecting the particular mix of KPIs that are most appropriate for a given project

TABLE 1. COMMONLY USED PERFORMANCE INCENTIVES FOR PROJECT EXECUTION

Health, safety and environmental performance (HSE)	Parameters related to LTI (lost-time incidents) or other HSE targets are often used as a reference metric to reflect overall HSE performance. This selection should be discussed and agreed upon with the owner, recognizing however that strong HSE performance should be a core value more than a commandment, and generally speaking should not need to be boosted by means of incentives
Quality (Q)	Quality in design is usually measured by tracking extra work and field rework percentages. However, as such fees are already included in the total installed cost KPI, establishing a separate incentive for Quality might turn into double dip of bonuses or penalties
Total installed cost	This is covered by means of the budget cost-definition mechanism described above and shown in Figure 4
Schedule (S)	Formalized schedule incentives can be established either for final dates, or for intermediate milestones, or for a combination of the two
Teamwork environment (TE) or innovative working processes	Using this qualitative incentive, the contractor agrees to be rewarded or penalized at the end of the project at the sole discretion of the owner based on agreed-upon terms. In other words, contractors will be judged by owners on the ability to create a sound cooperative climate throughout the project and to develop innovative working processes that are able to directly influence other parameters of the incentive program
Plant performance (P)	This incentive is designed to provide evidence of the reliability, availability and operability of the unit and of its flawless operation, on the basis of which one can establish related rewards or penalties

Note: The letter designations provided in Table 1 are used in the article text to illustrate the developing of a weighting scheme for incentives.

a result in a project that comes in on time and within budget.

FEL stage

The front-end loading stage of any capital-intensive project is a speculative period where the project funding is generally minimal (allocated funds are often specifically earmarked for the development of engineering services). Thus, during FEL, the incentives typically refer to "softer" parameters compared to incentives tied to more-specific deliverables during execution.

For instance, the incentives scorecard during the FEL project stage could include such metrics as the following:

- Cost compliance related to service during the FEL stage
- Estimated schedule versus actual outcome
- Overall benefit expected throughout the project cycle (these may include any reduction in total costs — fixed, variable or lifecycle — compared to expected values, schedule reduction from start to end of FEL, or any other important competitive advantage that may be introduced by the contractor during FEL)
- The owner's overall satisfaction (in terms of business aspects, technology, project, sites, and satisfaction with the perceived team integration with the contractor
- External benchmarking data to assess FEL completeness, accuracy

Execution stage

During project execution, additional KPIs can and should be identified and tracked. Specifically, during this project stage, both owners and contractors typically track performance objectives related to the following:

- Safety performance
- Total installed cost
- Schedule
- Overall teamwork environment or innovative working processes (examples include any innovative project-execution development or technological innovation introduced by contractor)

Self-funded incentives

Figure 4 and the discussion that follows help to explain the concept of developing performance incentives that are self-funded.

When developing a slate of targets to encourage the development and execution of capital-intensive projects, owners and contractors typically agree to the following:

- Work together to establish a project budget based on an open-book estimate approach (that is, a budgeted estimate that is jointly prepared and shared by owner and contractor at the end of FEL); this budget would include all project-execution costs and therefore even all the owner's ones
- Allocate the relevant project contingencies appropriately

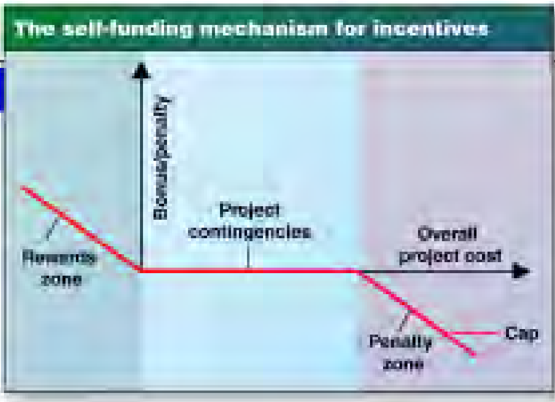

FIGURE 4. This figure shows the capital-cost outcome versus the budget value and its effect on the bonus or penalty incentives established for the contractor. The established cap is a function of the type of contract deal established between owner and contractor

- Work out a bonus/penalty diagram (such as the one presented in Figure 4) defining the incentive outcome for the contractor based upon the capital cost outcome of the project versus the budget value
- Agree on limiting the contractor's potential exposure to possible cost overruns beyond project contingencies, with a cap established as a function of the nature of the contract (for instance, in a reimbursable services contract, the subject cap should not overcome its fee, given the potential profit gained by the contractor)
- Participate in jointly agreed initiatives to realize overall cost savings

Apart from the capital cost incentives, owners would then fund their performance-incentive program for the other agreed-upon metrics using funds derived from any capital savings realized during project execution, and in some cases, using this pool of funds in full.

Using this approach brings the following benefits:

- The overall incentive program would be implemented at no additional cost for the owner
- The contractor would have the incentive to focus on controlling the overall budget, irrespective of the type of contractual deal established with the owner (namely it would exert a "lump-sum type behavior," even if working in a reimbursable framework)

It is important to note that during the project-execution stage, all parties should always consider the most appropriate metrics that are aimed at creating the safest workplace possible, while meeting project budget and schedule. Table 1 summarizes the features of some commonly used incentives that are often used during this project stage.

The incentives shown in Table 1 could be treated individually, or could be combined into a balanced formula based upon weights assigned by the owner. The various weights are meant to reflect the relative importance of each parameter in the context of a given project.

The final outcome of the incentives program for the contractor could result from a sample structure such as the one shown below (Note: This case assumes positive results, otherwise penalties would instead apply, as shown in Figure 4):

Bonus for total installed cost:
X% (to be defined) of capital cost saving based upon the agreed slope in Figure 4.

Bonus for all the other incentives, weighted:
$Y = (a \cdot HSE) + (b \cdot Q) + (c \cdot S) + (d \cdot TE) + (e \cdot P)$
The lower-case letters designate the weights to be established by the owner, and with a cap related to the owner's sharing of capital cost savings; the upper-case letters refer to specific incentives, as identified in Table 1.

Final thoughts

For any capital-intensive project, the ability to track relevant incentives helps to establish material proof of the proper performance of both the owner's and the contractor's respective project teams.

Open communications among owners and contractors, collaboration in selecting the most appropriate KPIs, and an effort to ensure transparency in the contractual arrangements established among the parties are essential to make this model work. When properly selected and transparently shared among all stakeholders, the use of KPIs can positively impact the overall teamwork environment and help all parties to achieve their safety and business goals. ■

Edited by Suzanne Shelley

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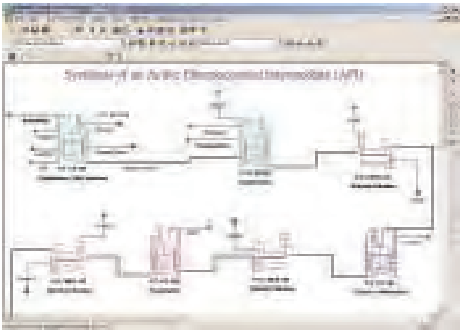

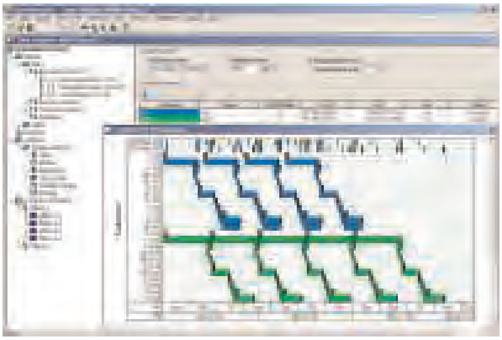

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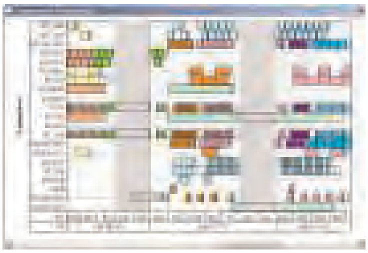

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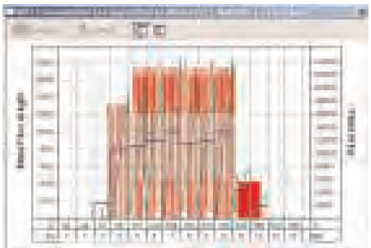

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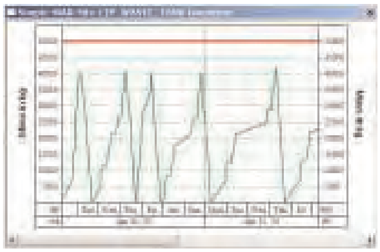

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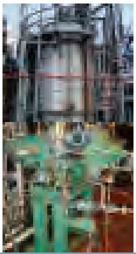

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51 Solids Handling Equipment
52 Tanks, Vessels, Reactors
53 Valves
54 Engineering Computers/Software/Peripherals
55 Water Treatment Chemicals & Equipment
56 Hazardous Waste Management Systems
57 Chemicals & Raw Materials
58 Materials of Construction
59 Compressors

1	16	31	46	61	76	91	106	121	136	151	166	181	196	211	226	241	256	271	286	301	316	331	346	361	376	391	406	421	436	451	466	481	496	511	526	541	556	571	586
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

Eurecat to build a new catalyst-processing facility in India

January 4, 2011 — Eurecat SA (La Voulte, France; www.eurecat.com), a joint venture of IFP Investissements and Albemarle Corp., is constructing a new, catalyst processing plant in India. WIth an expected commissioning during the 2nd quarter 2012, this plant will be dedicated to the ex situ regeneration of spent catalysts and associated services, as well as field services tools for industrial reactor turnarounds.

Styron to expand its solution styrene-butadiene rubber production in Germany

December 20, 2010 — Styron (www.styron.com) will expand its solution-styrene-butadiene rubber (SSBR) capacity with a new production line at its facility in Schkopau, Germany. The additional capacity of 50,000 m.t. is expected to start in the 4th Q of 2012.

Aker Solutions to provide FEED for Gasification/liquefaction plant in U.S.

December 19, 2010 — Medicine Bow Fuel & Power LLC has awarded Aker Solutions (www.akersolutions.com) the front-end engineering and design (FEED) package for its Medicine Bow Industrial Gasification & Liquefaction Plant located in Wyoming. The facility is due to come on line in 2015, and when complete, the plant will be capable of converting coal into 21,000 bbl/d of gasoline and LPG liquid fuels.

BASF expands its superabsorbent polymer production

December 17, 2010 — BASF SE (Ludwigshafen, Germany; www.basf.com) plans to expand its superabsorbent polymer production capacities at its Antwerp, Belgium and Freeport, Tex. sites. Debottlenecking and technical expansion measures are expected to raise capacity by 70,000 m.t./yr (35,000 m.t./yr by each site) to a total of 470,000 m.t. /yr by 2012.

Stamicarbon plans new urea production plant in China

December 17, 2010 — Stamicarbon B.V. (Sittard, the Netherlands; www.stamicarbon.com), the licensing and IP Center of Maire Tecnimont S.p.A. (www.mairetecnimont.it), has signed a license agreement with Inner Mongolia Bodashidi Co., Ltd. of the Peoples' Republic of China (PRC) for a urea plant with a capacity of 2,860 m.t./d. The plant will be built in the Industrial Zone of Nalinriver, Wushen, Inner Mongolia. Startup is planned in 2013.

Dow plans new propylene glycol plant in Thailand

December 16, 2010 — The Dow Chemical Co. (Midland, Mich.; www.dow.com) plans to build a propylene glycol (PG) plant in Map Ta Phut, Thailand, with a production capacity of up to 150,000 ton/yr. The facility will utilize propylene oxide (PO) derived from the new, sustainable hydrogen peroxide to propylene oxide (HPPO) technology, developed jointly by Dow and BASF SE. The process was an honoree of *Chemical Engineering's* Kirkpatrick Award in 2009 (*CE*, December 2009, pp. 17–21; www.che.com/news/5303.html). The HPPO plant is being constructed as part of the integrated JV liquids cracker and derivatives project in Thailand with Siam Cement Group (SCG; www.scg.co.th).

Solvay studies construction of epichlorohydrin production

December 14, 2010 — Solvay S.A. (Brussels, Belgium; www.solvay.com) is looking into the construction of an epichlorohydrin production plant in Taixing, China, with an initial capacity of 100,000 ton/yr. The plant, which is expected to start producing in 2013, will be based on Solvay's innovative Epicerol technology (also a Kirkpatrick Award honoree in 2009).

Foster Wheeler awarded contract for two Petrobas grassroots refineries in Brazil

December 13, 2010 — Foster Wheeler AG (FWC; Zug, Switzerland; www.fwc.com) has been awarded a FEED contract for two grassroots petroleum refineries in Brazil for Petróleo Brasileiro S.A., (Petrobras). The Premium I Refinery will be a dual train, 600,000 barrels per stream day (bpsd) facility, and the Premium II Refinery will be a single-train 300,000 bpsd facility. Foster Wheeler will be the prime subcontractor to UOP (Des Plains, Ill.; www.uop.com), the managing process-technology licensor.

Wacker plans new polysilicon-production facility in Tennessee

December 9, 2010 — Wacker Chemie AG (Munich, Germany; www.wacker.com) will build a new polysilicon production site near the city of Cleveland, Tenn. With a capacity of 15,000 m.t./yr, the production complex`s completion is expected at the end of 2013. The group has budgeted investments of some €1.1 billion for this expansion.

MERGERS AND ACQUISITIONS

DuPont to acquire Danisco to create world leader in industrial biotechnology

January 10, 2011 — DuPont (Wilmington, Del.; www.dupont.com) has entered into a definitive agreement for the acquisition of Danisco, a global enzyme and specialty food ingredients company, for $5.8 billion in cash and assumption of $500 million of Danisco's net debt. The transaction is expected to close early in the 2nd Q (for more, see the Chementator section on p. 11).

Axens to acquire Criterion's catalytic reforming business

January 6, 2011 — Axens North America Inc. (Princeton, N.J.; www.axens.net) has agreed to purchase the catalytic reforming catalyst business of Criterion Catalysts & Technology LP (Houston; www.criterioncatalysts.com). Under the deal, Axens will acquire Criterion's Willow Island, W.Va. manufacturing plant, where reforming catalysts are made. The relevant intellectual property rights required to pursue the catalytic reforming business is also part of the agreement. The sale terms were not disclosed.

CB&I acquires 100% interest in Catalytic Distillation Technologies

January 4, 2011 — CB&I (The Woodlands, Tex.; www.cbi.com) has acquired Chemical Research and Licensing from CRI/Criterion, a subsidiary of Royal Dutch Shell plc. This acquisition gives CB&I, through its Lummus Technology business sector, a 100% interest in Catalytic Distillation Technologies (CDTech; Houston; www.cdtech.com). Prior to this acquisition, CB&I held a 50% interest in CDTech. The acquisition closed on December 31. The terms were not disclosed

Lanxess reaches agreement to acquire DSM Elastomers

December 14, 2010 — Lanxess AG (Leverkusen, Germany; www.lanxess.com) and Royal DSM N.V. (Heerlen, the Netherlands; www.dsm.com) have reached an agreement involving the sale of DSM Elastomers to Lanxess for €310 million on a cash and debt-free basis. The transaction contracts will be finalized once a consultation process with the employees' representatives of DSM in the Netherlands has been completed. The transaction is subject to approval from antitrust authorities. Closing is expected in the first months of 2011. ■

Dorothy Lozowski

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

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Economic Indicators

2010 2009 2008

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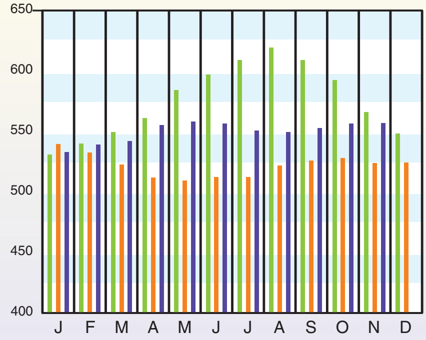
CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957-59 = 100)	Nov.'10 Prelim.	Oct.'10 Final	Nov.'09 Final
***CE* Index**	556.8	556.3	523.6
Equipment	669.0	667.5	618.0
Heat exchangers & tanks	618.3	617.8	556.1
Process machinery	626.8	627.0	601.1
Pipe, valves & fittings	847.0	840.2	768.2
Process instruments	426.4	426.0	413.5
Pumps & compressors	904.0	902.5	895.2
Electrical equipment	487.1	484.7	465.9
Structural supports & misc	688.2	689.6	624.2
Construction labor	329.1	331.0	329.6
Buildings	501.3	503.3	493.0
Engineering & supervision	336.1	336.6	343.8

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

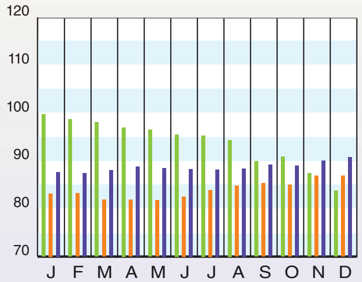
Starting with the April 2007 Final numbers, several of the data series for labor and compressors have been converted to accommodate series IDs that were discontinued by the U.S. Bureau of Labor Statistics



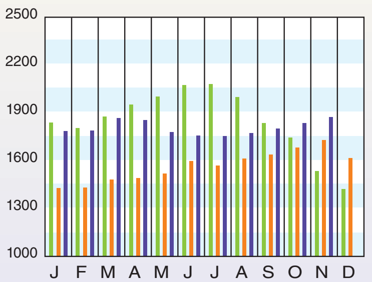
CURRENT BUSINESS INDICATORS

	LATEST	PREVIOUS		YEAR AGO
CPI output index (2007 = 100)	Dec.'10 = 90.8	Nov.'10 = 90.0	Oct.'10 = 89.0	Dec.'09 = 86.9
CPI value of output, $ billions	Nov.'10 = 1,874.7	Oct.'10 = 1,836.7	Sep.'10 = 1,802.8	Nov.'09 = 1,730.5
CPI operating rate, %	Dec.'10 = 73.6	Nov.'10 = 72.8	Oct.'10 = 71.9	Dec.'09 = 69.6
Producer prices, industrial chemicals (1982 = 100)	Dec.'10 = 282.8	Nov.'10 = 276.0	Oct.'10 = 267.6	Dec.'09 = 254.6
Industrial Production in Manufacturing (2007=100)	Dec.'10 = 92.0	Nov.'10 = 91.6	Oct.'10 = 91.4	Dec.'09 = 86.9
Hourly earnings index, chemical & allied products (1992 = 100)	Dec.'10 = 154.7	Nov.'10 = 155.2	Oct.'10 = 157.2	Dec.'09 = 150.9
Productivity index, chemicals & allied products (1992 = 100)	Dec.'10 = 125.4	Nov.'10 = 123.7	Oct.'10 = 122.4	Dec.'09 = 118.2

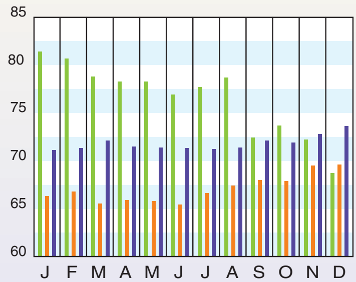
CPI OUTPUT INDEX (2007 = 100)



CPI OUTPUT VALUE ($ BILLIONS)



CPI OPERATING RATE (%)



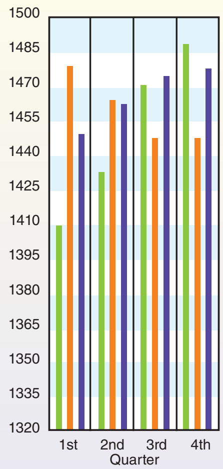
Current Business Indicators provided by Global Insight, Inc., Lexington, Mass.

MARSHALL & SWIFT EQUIPMENT COST INDEX

(1926 = 100)	4th Q 2010	3rd Q 2010	2nd Q 2010	1st Q 2010	4th Q 2009
M & S INDEX	1,476.7	1,473.3	1,461.3	1,448.3	1,446.5
Process industries, average	1,537.0	1,534.4	1,522.1	1,510.3	1,511.9
Cement	1,532.5	1,530.0	1,519.2	1,508.1	1,508.2
Chemicals	1,507.3	1,505.2	1,493.5	1,481.8	1,483.1
Clay products	1,521.4	1,518.3	1,505.6	1,496.0	1,494.3
Glass	1,432.7	1,428.5	1,416.4	1,403.0	1,400.1
Paint	1,545.8	1,542.1	1,527.6	1,515.1	1,514.1
Paper	1,447.6	1,444.5	1,430.1	1,416.4	1,415.8
Petroleum products	1,640.4	1,637.0	1,625.9	1,615.6	1,617.6
Rubber	1,581.5	1,579.3	1,564.2	1,551.0	1,560.5
Related industries					
Electrical power	1,434.9	1,419.2	1,414.0	1,389.6	1,377.3
Mining, milling	1,579.4	1,576.7	1,569.1	1,552.1	1,548.1
Refrigeration	1,809.3	1,804.8	1,786.9	1,772.2	1,769.5
Steam power	1,506.4	1,502.3	1,488.0	1,475.0	1,470.8

Annual Index:

2003 = 1,123.6	2004 = 1,178.5	2005 = 1,244.5	2006 = 1,302.3
2007 = 1,373.3	2008 = 1,449.3	2009 = 1,468.6	2010 = 1,457.4



CURRENT TRENDS

Capital equipment prices (as reflected in the *CE* Plant Cost Index) increased from October to November. Meanwhile, Global Insight's CPI output index, CPI value of output and CPI operating rate all increased in November and December.

According to the American Chemistry Council's (Arlington, Va.; www.americanchemistry.com) most-recent weekly economic report at *CE* press time, U.S. chemical production rose 0.5% in December, following a 0.6% gain in November, while global chemical industry production continued to expand by 0.5%.

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