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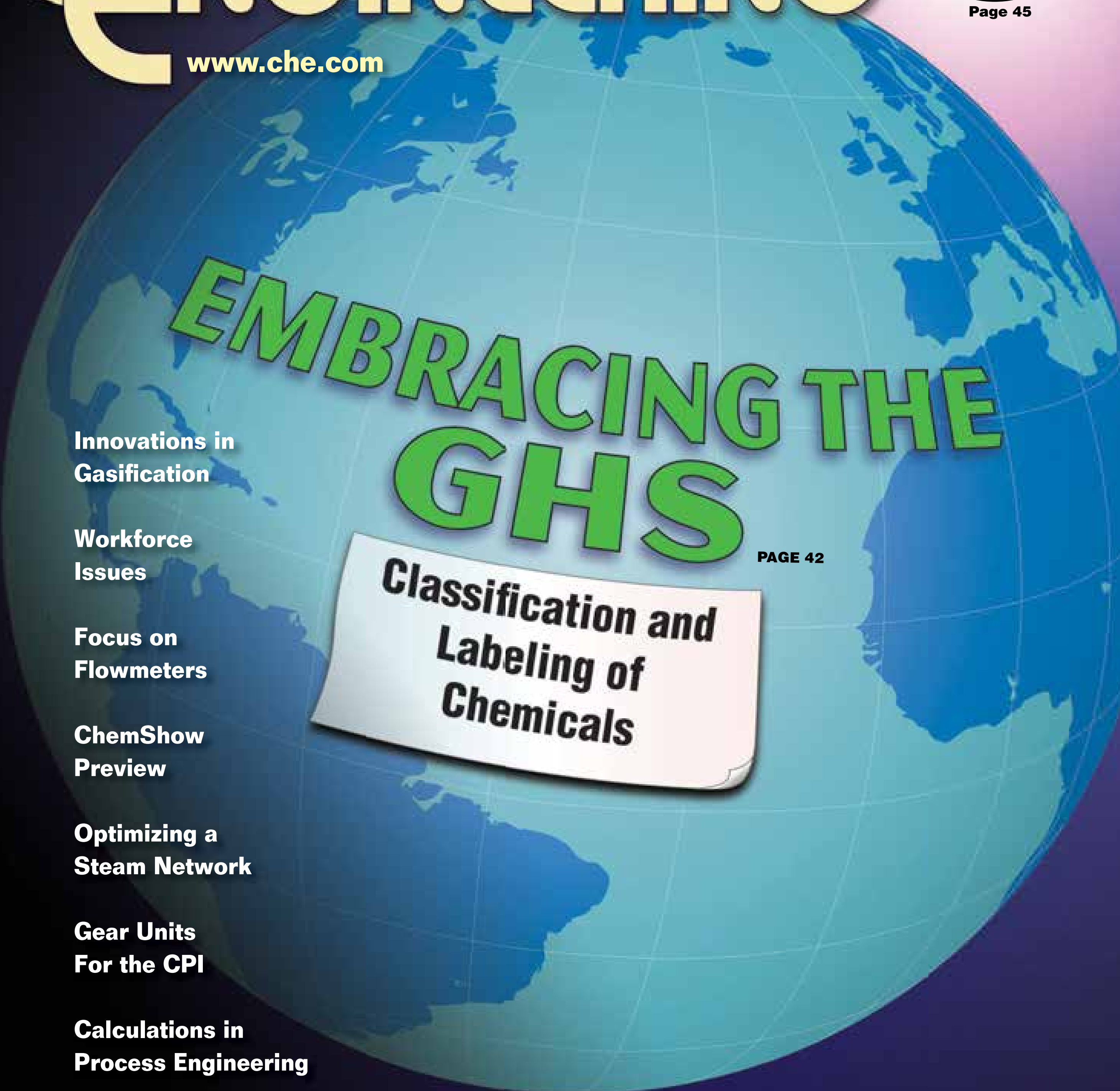

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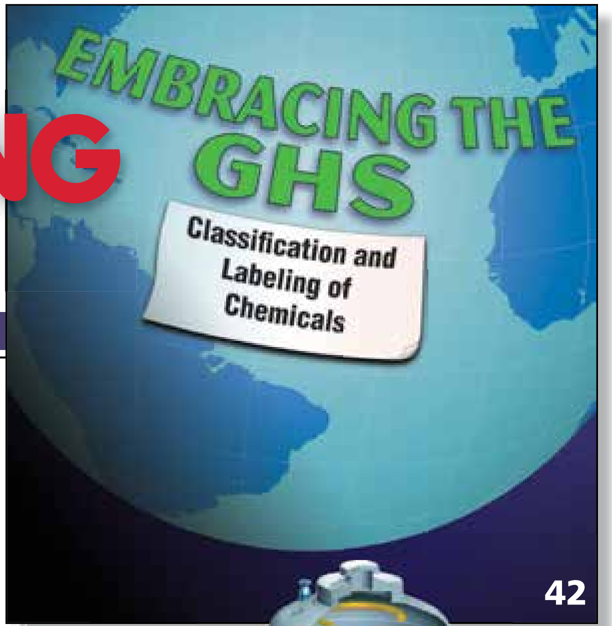

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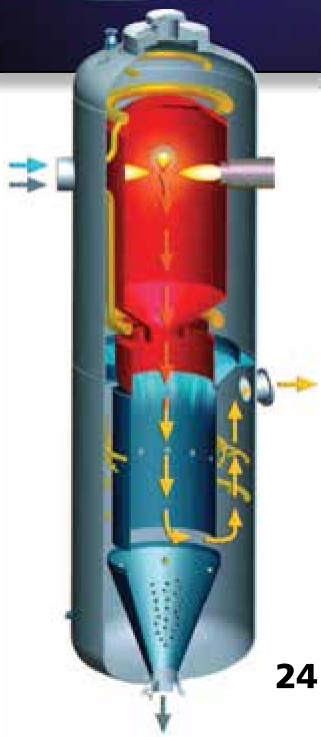
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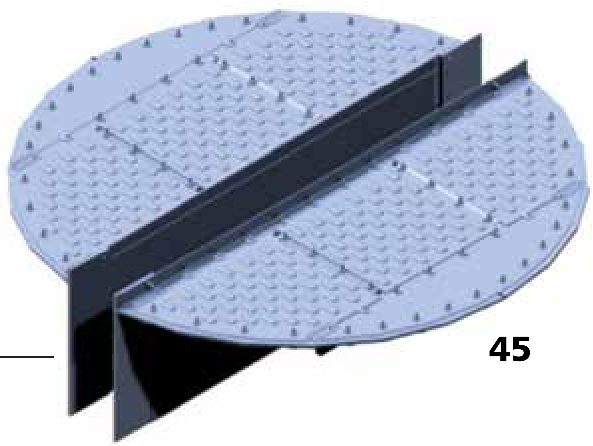
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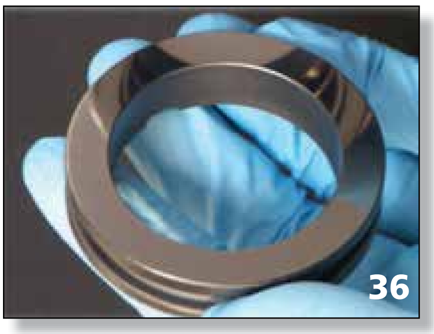

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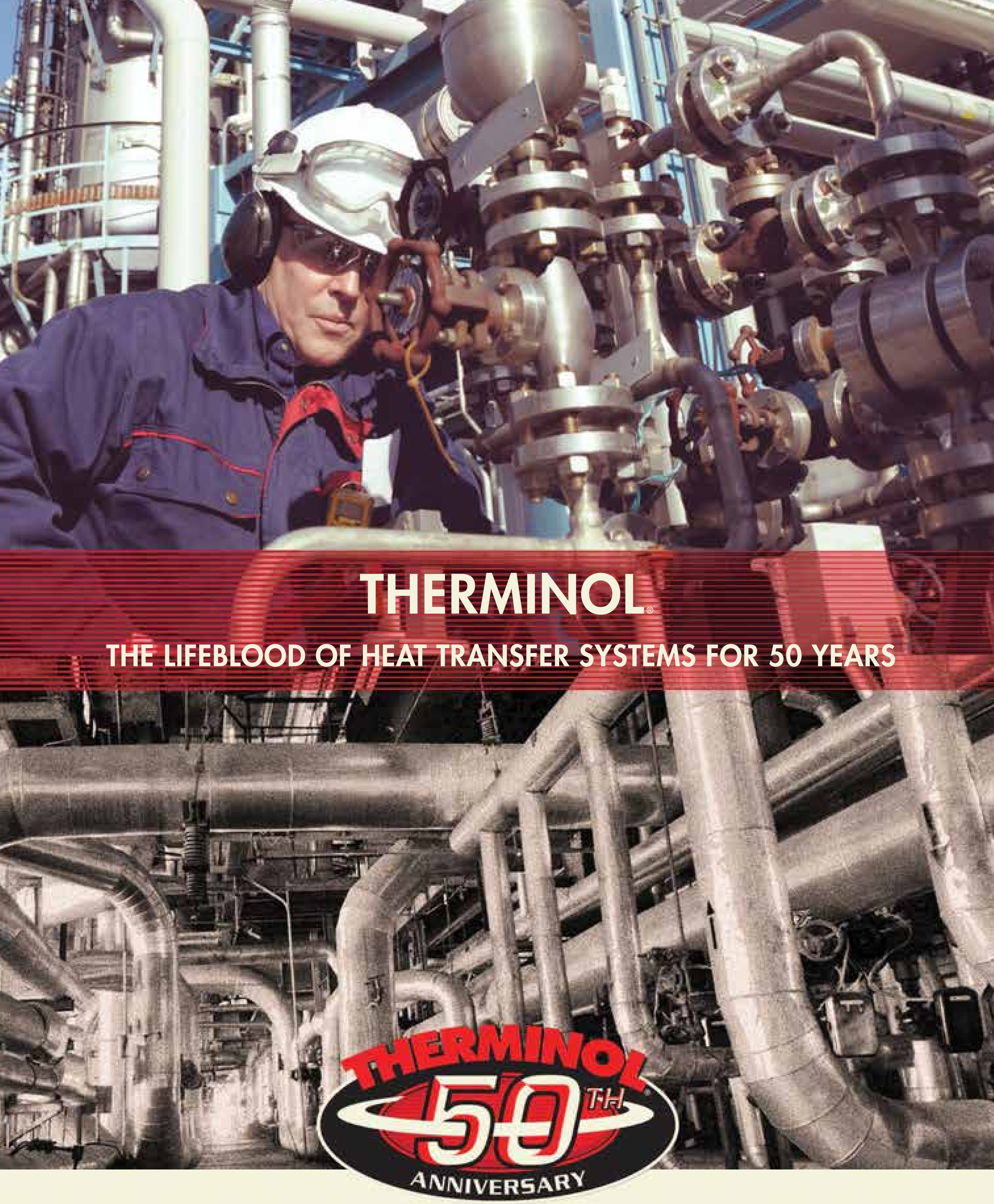

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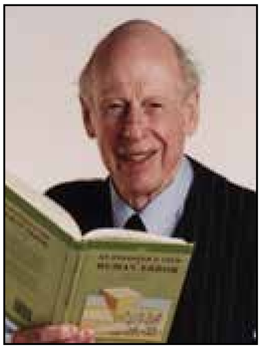
Editor's Page

A tribute to a safety trailblazer



IChemE

One of the chemical process industries' (CPI) foremost authorities on process safety, Trevor Kletz, passed away in late October at the age of 91.

Amongst Kletz's many achievements, one that stands out is his extensive contributions to the concept of inherent safety — a technique to reduce plant hazards through design, for example by keeping a lower inventory of hazardous chemicals on hand and using chemicals in a safer-to-handle form. In a statement about Kletz, the U.S. Chemical Safety Board (CSB; Washington, D.C.; www.csb.org) said "Dr. Kletz's career in industry established him as an expert in chemical process safety, safety culture, and as an advocate — indeed the father of — the concept of inherently safer technology and processes. One of his seminal papers was entitled 'What You Don't Have Can't Leak.' His teachings on accident investigations refocused the emphasis from individual lapses to systems failures and safer design." The full statement from the CSB, as well as a video that features an interview with Kletz, can be found on the CSB's website.

Another outstanding endeavor attributed to Kletz is his role in further developing and championing hazard and operability studies (Hazops) — a technique for identifying potential hazards in plants. In 1985, he authored an article for this magazine that detailed Hazops and Hazans, which are hazard analyses that work out the probability of an accident and the extent of the consequences, and compare them to a target (Eliminating Potential Process Hazards, *Chem. Eng*., pp. 48–68, April 1985).

Kletz started his professional journey with a chemistry degree from Liverpool University in 1944. He then moved on to a long-time distinguished career with Imperial Chemical Industries (ICI), where he became the safety advisor to the then Heavy Organic Chemicals Div. — one of the first such appointments in the U.K. Kletz established a close relationship with the Dept. of Chemical Engineering at the University of Technology in Loughborough, Leicestershire, where he eventually served as a professor and was granted a doctoral degree in chemical engineering in 1986.

In 1990, Trevor Kletz received this magazine's Award for Personal Achievement in Chemical Engineering. At that time, the pages of this magazine said about Kletz that "His main job satisfaction comes from spreading knowledge — including the particulars of specific accidents — in a way that has a useful impact" (Fresh Honor for Three Engineers, *Chem. Eng*., p. 93, December 1990).

Indeed, Kletz is noted for sharing his knowledge in a very practical way. In a review of one of Kletz's books "Process Plants: A Handbook for Inherently Safer Design," published in 1998, Ian Sutton wrote, "As we have come to expect from all of this author's works, the ideas that he presents are illustrated with a wide variety of practical, industrial examples. What is noteworthy about many of the examples is that they do not necessarily spend a lot of money — they simply involve thinking creatively" (Bookshelf, *Chem. Eng*., June 1999).

In a recent statement, IChemE chief executive David Brown said, "Trevor unquestionably saved lives. There are people working in the process industries today who will go home safely to their families and loved ones, thanks to Trevor. He had a profound impact on industrial safety." We thank you, Trevor Kletz. ■

Dorothy Lozowski, Editor in Chief

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PUBLISHER

MICHAEL GROSSMAN
Vice President and Group Publisher
mgrossman@accessintel.com

EDITORS

DOROTHY LOZOWSKI
Editor in Chief
dlozowski@che.com

GERALD ONDREY (Frankfurt)
Senior Editor
gondrey@che.com

SCOTT JENKINS
Senior Editor
sjenkins@che.com

MARY PAGE BAILEY
Assistant Editor
mbailey@che.com

CONTRIBUTING EDITORS

SUZANNE A. SHELLEY
sshelley@che.com

CHARLES BUTCHER (U.K.)
cbutcher@che.com

PAUL S. GRAD (Australia)
pgrad@che.com

TETSUO SATOH (Japan)
tsatoh@che.com

JOY LEPREE (New Jersey)
jlepree@che.com

GERALD PARKINSON
(California) gparkinson@che.com

MARKETING

MICHAEL CONTI
Marketing Director
TradeFair Group, Inc.
michaelc@tradefairgroup.com

ART & DESIGN

DAVID WHITCHER
Art Director/
Editorial Production Manager
dwhitcher@che.com

PRODUCTION

JOHN BLAYLOCK-COOKE
Ad Production Manager
jcooke@accessintel.com

INFORMATION SERVICES

CHARLES SANDS
Director of Digital Development
csands@accessintel.com

AUDIENCE DEVELOPMENT

SARAH GARWOOD
Audience Marketing Director
sgarwood@accessintel.com

GEORGE SEVERINE
Fulfillment Manager
gseverine@accessintel.com

JEN FELLING
List Sales, Statlistics (203) 778-8700
j.felling@statlistics.com

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Letters

Capital cost calculations

I recently read the article "Capital Costs Quickly Calculated" [*Chem. Eng.*, pp.46–52, April 2009] and find it extremely informative and useful.

I have reservations about the example given about the cost comparison of two spherical storage tanks.

The authors state that the costs of spherical storage tanks are proportional to surface area, therefore, to the quantity of metal plate used in fabrication. They came out with a size exponent of 2/3 and concluded doubling the size of a spherical storage tank increases its price by about 60%.

Here, the authors made a wrong assumption. They assumed the plate thickness remains the same irrespective of the size of tank.

As per relevant design codes, such as ASME-VIII, the thickness of a sphere or a cylindrical vessel is proportional to radius. Doubling the diameter means the thickness would be doubled.

Therefore the exponent of 2/3 is not valid. Accounting for the fact the thickness is proportional to the diameter, and tank steel weight is proportional to (i) tank area and (ii) tank wall thickness, the exponent would be 1 and not 2/3.

In other words, doubling the size of a spherical storage tank increases its price by about 100% and not 60%, as concluded by the erudite authors.

D. Gopalkrishna Murti
Operations Technical Services, Kuwait Oil Co., Kuwait

Editor's Note: A response from the authors is available online together with this letter at www.che.com

Postscripts, corrections

October 2013, "Advancing Battery Materials," pp. 17–23. In the portion of the article discussing the battery separator technology developed by Madico Inc. (Woburn, Mass.; www.madico.com), the material baumite (AlO_3) was incorrectly mentioned as a component of Madico's separator. The material should have been stated as boehmite, an aluminum oxide hydroxide, AlO(OH). The Madico separator is made by forming a nano-composite membrane with a specific crystalline form of boehmite bound within an organic polymer matrix.

October 2013, Focus on Packaging, p. 30. "Print compliant labels faster and with better quality," the name of the company and the email address were incorrectly spelled with an m in place of an n. The correct name is Epson America Inc. (http://pos.epson.com/colorworks).

The corrected versions of the full articles can be found at www.che.com. ■

Calendar

NORTH AMERICA

2014 Proactive Compliance Conference. International Soc. for Pharmaceutical Engineering (ISPE; Tampa, Fla.). Phone: 813-960-2105; Web: ispe.org
New Brunswick, N.J. **January 13–14, 2014**

Informex. UBM Live (Hamilton, N.J.). Phone: 609-759-4700; Web: informex.com
Miami, Fla. **January 21–24, 2014**

4th Annual Chem/Petrochem & Refinery Asset Reliability Conference. Marcus Evans North America Conferences (Chicago, Ill.). Phone: 312-540-3000, Ext. 6483; Web: marcusevansch.com
Houston **January 14–16, 2014**

4th Process Safety Management for Chem/Petrochem & Refining Industries Conference. Marcus Evans North America Conferences (Chicago, Ill.). Phone: 312-540-3000, Ext. 6483; Web: marcusevansch.com
Houston **January 14–16, 2014**

4th Annual Electric Energy Storage Conference. Marcus Evans North America Conferences (Chicago, Ill.). Phone: 312-894-6377; Web: marcusevansch.com
San Diego, Calif. **January 14–16, 2014**

ARC Industry Forum. ARC Advisory Group (Chicago, Ill.). Phone: 781-471-1000; Web: arcweb.com/events/arc-industry-forum-orlando
Orlando, Fla. **February 10–13, 2014**

ISPE 2014 Aseptic Conference. International Soc. for Pharmaceutical Engineering (ISPE; Tampa, Fla.). Phone: 813-960-2105; Web: ispe.org
Washington, D.C. **February 24–25, 2014**

Corrosion 2014. National Assn. of Corrosion Engineers (NACE) International (Houston). Phone: 281-228-6200; Web: nace.org
San Antonio, Tex. **March 9–13, 2014**

247th Annual ACS National Meeting. American Chemical Soc. (ACS; Washington, D.C.). Phone: 202-872-4600; Web: acs.org
Dallas, Tex. **March 16–20, 2014**

Interphex 2014. Reed Exhibitions (Norwalk, Conn.). Phone: 203-840-5603; Web: interphex.com
New York, N.Y. **March 18–20, 2014**

2014 AFPM Annual Meeting. American Fuel & Petrochemical Manufacturers (AFPM; Washington, D.C.). Phone: 202-457-0480; Web: afpm.org
Orlando, Fla. **March 23–25, 2014**

2014 AIChE Spring Meeting and 10th Global Congress on Process Safety. AIChE (New York, N.Y.).

Phone: 203-702-7660; Web: aiche.org
New Orleans, La.. **March 30–April 3, 2014**

Electric Power. Tradefair Group, An Access Intelligence LLC Co. (Houston). Phone: 713-343-1893; Web: electricpowerexpo.com
New Orleans, La. **April 1–3, 2014**

Battcon 2014 Stationary Battery Conference and Trade Show. Albercorp/Battcon (Pompano Beach, Fla.). Phone: 954-623-6660; Web: battcon.com
Boca Raton, Fla. **May 5–7, 2014**

Identify, Characterize, Select and Isolate the Optimal Solid State Form for Pharmaceutical Development. Scientific Update (East Sussex, U.K.), in conjunction with Crystal Pharmatech (Princeton, N.J.) and Rutgers University (New Brunswick, N.J.). Phone: +44-1435-873062; Web: scientificupdate.co.uk
New Brunswick, N.J. **May 15–16, 2014**

EUROPE

10th Energy Efficiency & Renewable Energy Congress and Exhibition for Southeast Europe.Via Expo Ltd. (Plovdiv, Bulgaria). Phone: +359-32-512-900; Web: via-expo.com/en/pages/ee-re-exhibition
Sofia, Bulgaria **March 5–7, 2014**

5th Conference and Exhibition on Waste Management, Recycling, Environment for South-East Europe. Via Expo (Plovdiv, Bulgaria). Phone: Phone: +359-32-512-900; Web: via-expo.com
Sofia, Bulgaria **March 5–7, 2014**

SEE Solar — South-East European Solar PV & Thermal Exhibition. Via Expo (Plovdiv, Bulgaria). Phone: Phone: +359-32-512-900; Web: via-expo.com
Sofia, Bulgaria **March 5–7, 2014**

New Horizons in Gasification. Institution of Chemical Engineers (IChemE; Rugby, U.K.). Phone: +44-1788-534489; Web: icheme.org/gasification2014
Rotterdam, The Netherlands **March 10–13, 2014**

In-Cosmetics 2014. Reed Exhibitions Ltd. (Richmond, U.K.). Phone: +44-20-8271-2122; Web: in-cosmetics.com
Hamburg, Germany **April 1–3, 2014**

Hannover Messe 2014. Hannover Messe AG (Hannover, Germany). Phone: +49-511-89-0; Web: hannovermesse.de
Hannover, Germany. **April 7–11, 2014**

ASIA & ELSEWHERE

Chemeca 2014. Institution of Chemical Engineers (IChemE; Rugby, U.K.); Phone: +44-1788-534489; Web: chemeca2014.com
Perth, Australia **Sept. 28–Oct. 1, 2014** ■

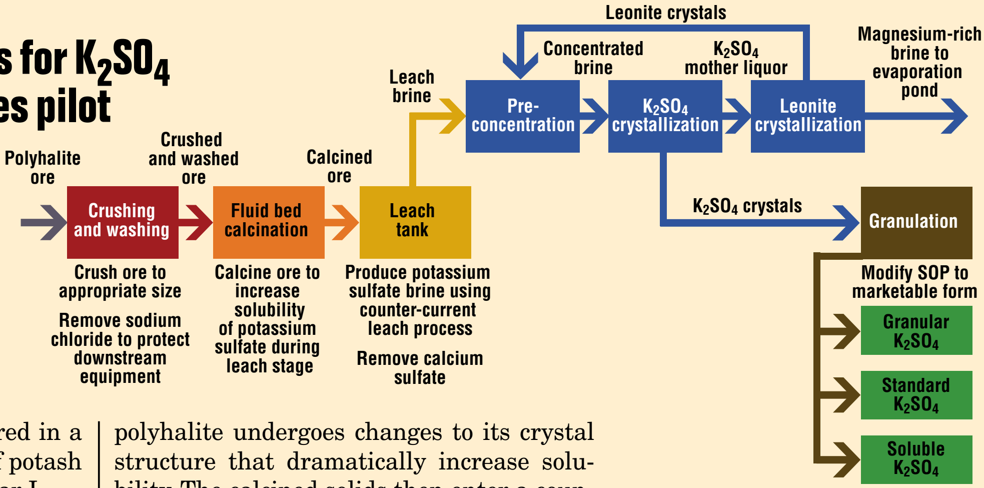
Suzanne Shelley

CHEMENTATOR

Edited by Gerald Ondrey

December 2013

First commercial process for K_2SO_4 from polyhalite completes pilot



Pilot plant operation has been completed for a process that produces the fertilizer potassium sulfate from the mineral polyhalite, a hydrated sulfate of potassium, magnesium and calcium. The process, developed by Intercontinental Potash Corp. (ICP; Golden, Colo.; www.icpotash.com), resurrects a route to K_2SO_4 that was first explored in a push to develop a domestic source of potash after a German embargo in World War I.

"Although it was evaluated decades ago, but not pursued, our process represents the first commercially viable potassium sulfate process using mined polyhalite as a feedstock," says Randy Foote, chief operating officer at ICP. "After validating the decades-old data, ICP developed a patented hybrid crystallization system designed to maximize production of K_2SO_4," explains ICP process engineer Mike Morrison.

The ICP process avoids the cost fluctuations of conventional potassium sulfate production, where feedstocks potassium chloride and sulfuric acid must be purchased. ICP's polyhalite route is less expensive than using mined sylvite, a naturally occurring mineral composed of KCl, Foote says.

The process (flowsheet) begins with a crushing and washing stage to remove sodium chloride, then enters a calcination step in a fluidized-bed reactor, where the polyhalite undergoes changes to its crystal structure that dramatically increase solubility. The calcined solids then enter a countercurrent leaching process that removes potassium and magnesium sulfate from the mineral, forming a brine.

The next stage of the process involves a hybrid crystallization system that combines mechanical vapor recompression (MVR) and multiple effect evaporation (MEE). The patented circuit features a leonite dissolver, which takes a potassium- and magnesium-containing mineral (leonite) from later in the process and uses it to increase production of potassium sulfate. An MVR evaporator removes water until the K_2SO_4 crystallizes, recovering 90% of the material. The mother liquor then enters a series of MEEs, which produce the leonite that is then recirculated (U.S. Patent 8,551,429; other patents pending).

The final stage of the process is a drying and granulation step, where three potassium sulfate products are produced — standard, granular and soluble-grade.

Improving extraction yields of Ni and Co from laterite

Low-grade nickel (less than 1.5 wt.%) laterite ores represent about 70% of global reserves but account for only 40% of nickel production. Increasing demand for nickel in recent years has created the need to process such ores. Atmospheric acid leaching of these ores presents difficulties due to the presence of high-acid-consuming serpentinized and clay minerals, leading to pulp gelation and poor mixing, and low metal recovery. Now a team from the Ian Wark Research Institute, University of South Australia (Adelaide: www.unisa.edu.au), led by professor Jonas Addai-Mensah, has shown how to increase Ni and Co recoveries from these ores.

The team studied the influence of time and temperature on atmospheric acid-leaching behavior of saprolitic nickel laterite ores. It carried out isothermal (at 70°C and 95°C), batch, sulfuric acid leaching studies on 40 wt.% solid dispersions of 2-mm saprolitic nickel laterite ore for 4 h at pH=1.

There was a sharp decrease in particle size within the first 5 min. of shearing in both water and sulfuric acid. This was accompanied by an increase in the amount of finer particles in the pulps. Further increase in time led to a gradual decrease in size for the particles sheared in water with a marginal change in the acidic solution.

The specific surface areas at 120 and

(*Continues on p. 12*)

Acetic acid from syngas

A new process for the production of acetic acid claims to be more efficient and cost-effective than current technologies. Carbonylation of methanol has been the leading acetic acid technology for several decades, but BP plc (London, U.K.; www.bp.com) has introduced the new three-step SaaBre process to produce acetic acid directly from synthesis gas (syngas; a mixture of H_2 and CO).

Unlike current acetic acid technologies, the SaaBre process requires no CO purification, and no methanol needs to be purchased. Also, there are no iodides present, reducing the need for any metallurgical considerations. In fact, experts believe that SaaBre will cut variable operating costs over BP's current methanol-carbonylation technology to produce acetic acid, Cativa XL, by up to \$50 per metric ton.

Another feature of the process is its ability to use simple, ample feedstocks. Creating products directly from syngas allows for numerous suitable feedstock sources in any region around the world. The inaugural deployment of the SaaBre technology is expected for the first half of 2014, with future plans includ-

(*Continues on p. 13*)

Note: For more information, circle the 3-digit number on p. 68, or use the website designation.

An efficient way to make fermentable sugars from fibrous waste

The National Food Research Institute (NFRI) of the National Agriculture and Food Research Organization (NARO; Tsukuba City, Japan; www.naro.affrc.go.jp) has developed an enzymatic pretreatment process for producing highly concentrated sugar solution from fibrous materials containing rice straw and starch. The process can be used for producing specific sugar solutions, depending on the local raw materials, such as discharged residue from the food factories.

The researchers have modified the so-called CaCCO process [(calcium capturing by carbonation (CO_2)] process — developed by Park and colleagues in 2010 to handle herbaceous lignocellulosics — in order to recover fermentable sugars from rice straw (RS) and stems and leaves of *Erianthus arundinaceus* (ER), one of the strategic energy crops in Japan.

In the process, a mixture of feedstock, water and $Ca(OH)_2$, (relative weight ratios of 3:7:0.3) is continuously milled under relatively mild temperatures of 95–100°C. Enzymatic-saccharification tests were performed for the pretreatment slurries from 10 kg feedstocks for 72 h at 40°C under a pressurized CO_2 atmosphere of 0.9 MPa. Using high-solid loadings of 28.4% (w/w) for RS and 27.8% (w/w) for ER, the researchers successfully solubilized 80.6% (RS) and 68.1% (ER) of the total glucose and xylose residues from the solids. After centrifugation, the solubilized-sugar concentrations in the recovered solutions were 16.9% (w/v) for RS and 15.5% (w/v) for ER. The results are comparable to that achieved by conventional pretreatment methods that use concentrated sulfuric acid at high temperature (100°C).

NFRI says the method offers a simpler and "greener" alternative to existing technologies, and could be used to revitalize rural areas by utilizing waste crops for local fermentation industries, such as for making sake alcohol and miso bean pastes.

NI AND CO FROM LATERITE

(*Continued from p. 11*)

240 min. were 24 and 26.7 m^2/g, respectively, at 70°C; and 45.1 and 144.4 m^2/g, respectively, at 95°C. The dispersions presented a clear time-dependent rheological behavior with high yield stresses and viscosities, which increased with time and decreased with temperature.

Ni and Co recoveries, which were less than 25% at 70°C, increased to 89% and 78%, respectively, at 95°C. Average sulfuric acid consumption was 200 kg/ton at 70°C and 700 kg/ton at 95°C.

(*Continued from p. 11*)

ing the capability to produce methanol and ethanol from the process as well.

Biobutanol

The Industrial Technology Research Institute (ITRI; Hsinchu, Taiwan; www.itri.org.tw) has developed a process to make fuel-grade butanol with a negative carbon footprint. The so-called ButyFix technology is a three-step process. First, cellulose and hemicellulose are converted into fermentable sugars by a solvent-based hydrolysis. The sugars are then fermented into butyrate, which is then esterified and hydrogenated into butanol. Unlike conventional fermentation processes that generate CO_2, the microorganisms used in ButyFix process can reuse CO_2 generated in the fermentation, resulting in a high carbon-fixation performance.

The process has achieved a butyrate yield of 0.7 g per gram of sugar, which is said to

(*Continues on p. 14*)

Metabolic engineering makes plants produce more oils

A research team from the University of Western Australia (Perth; www.uwa.edu.au), led by professor Dongke Zhang, has pioneered the application of higher plants for new-generation biofuel production. Metabolic engineering of *Arabidopsis thaliana* — a small flowering plant native to Europe and Asia, which was the first plant to have its genome sequenced — caused the plant to produce triterpene hydrocarbons. The team cloned a gene — a triterpene methyltransferase 3 (BbTMT-3) — from the microalga *Botryococcus braunii* and transferred it to *Arabidopsis thaliana*.

The microalga can produce extracellular oil in the form of triterpenoid hydrocarbons up to 40 wt.% (dry). These hydrocarbons with chain lengths of C30 to C40, which include botryococcene, squalene and methylated squalenes, are suitable for producing liquid transport fuels and petrochemical alternatives.

However, commercial-scale production of the alga is hampered by its slow growth rate. Other fast-growing microalgae and terrestrial plants do not accumulate triterpene hydrocarbons, because squalene, a key metabolite of the plant's triterpene pathway, is rapidly converted to downstream products. Squalene ($C_{30}H_{50}$) is the starting molecule for all triterpenoids and has been identified in almost all plant species, but usually in very small amounts.

The team therefore employed a metabolic engineering approach to divert the plant triterpene pathway for hydrocarbon production. The BbTMT-3 was found to add methyl groups to squalene, preventing it from being further metabolized. The transgenic plants contained 30 µg/g fresh weight of monomethylsqualene and 50 µg/g of dimethylsqualene. These new hydrocarbons were not present in untransformed plants.

The team says it has demonstrated the feasibility of new biofuel production via metabolic engineering. It said the knowledge gained from its experiments can be easily applied to other organisms, such as fast-growing microalgae.

This gasification process turns waste into syngas

Construction of a large-scale waste-to-energy plant will start in the middle of next year in Port Hedland, Western Australia, and operation is scheduled to commence in the second quarter of 2015. The plant will be built by the New Energy Corp. (Perth; www.newenergycorp.com.au), and will employ low-temperature gasification technology invented and developed by Western Australian company Entech Renewable Energy Solutions Pty. Ltd. (Canning Vale, Western Australia; www.entech-res.com).

The 72-MW_{th} facility will initially process about 100,000 ton/yr, but will eventually be able to process up to 200,000 ton/yr of various mixed waste streams, including municipal solid waste (MSW), and materials such as plastic bags and wrapping, textiles, contaminated cardboard, timber packaging from construction and demolition projects, and used tires, and export 15.5 MW of power to the grid. Much of the waste would otherwise go to landfill.

Entech says its technology, called WtGas, converts solid waste to syngas — a mixture of H_2, CO, CH_4 and C_nH_n hydrocarbons — that can be fired to generate energy in a process with cleaner emissions than those resulting from firing any fossil fuel. In the process (flowsheet), the waste is slow-cooked at temperatures between 600 and 850°C for 16–24 h to provide a cleaner gas than that produced by incineration. The feedstock of the gasification process is subjected to regular churning and stoking by the company's patent-pending Churning, Stoking and Distribution System.

The company said the process is about 1/20th the air input and about 1/50th the velocity and turbulence of conventional combustion, which maximizes the volatility of the syngas, and minimizes pollution.

The system adopts conventional high-efficiency/low-NOx burner design with staged processes of pre-mixing to LEL (lower explosive limit), ignition and oxidation. The burner also destroys most persistent organic pollutants.

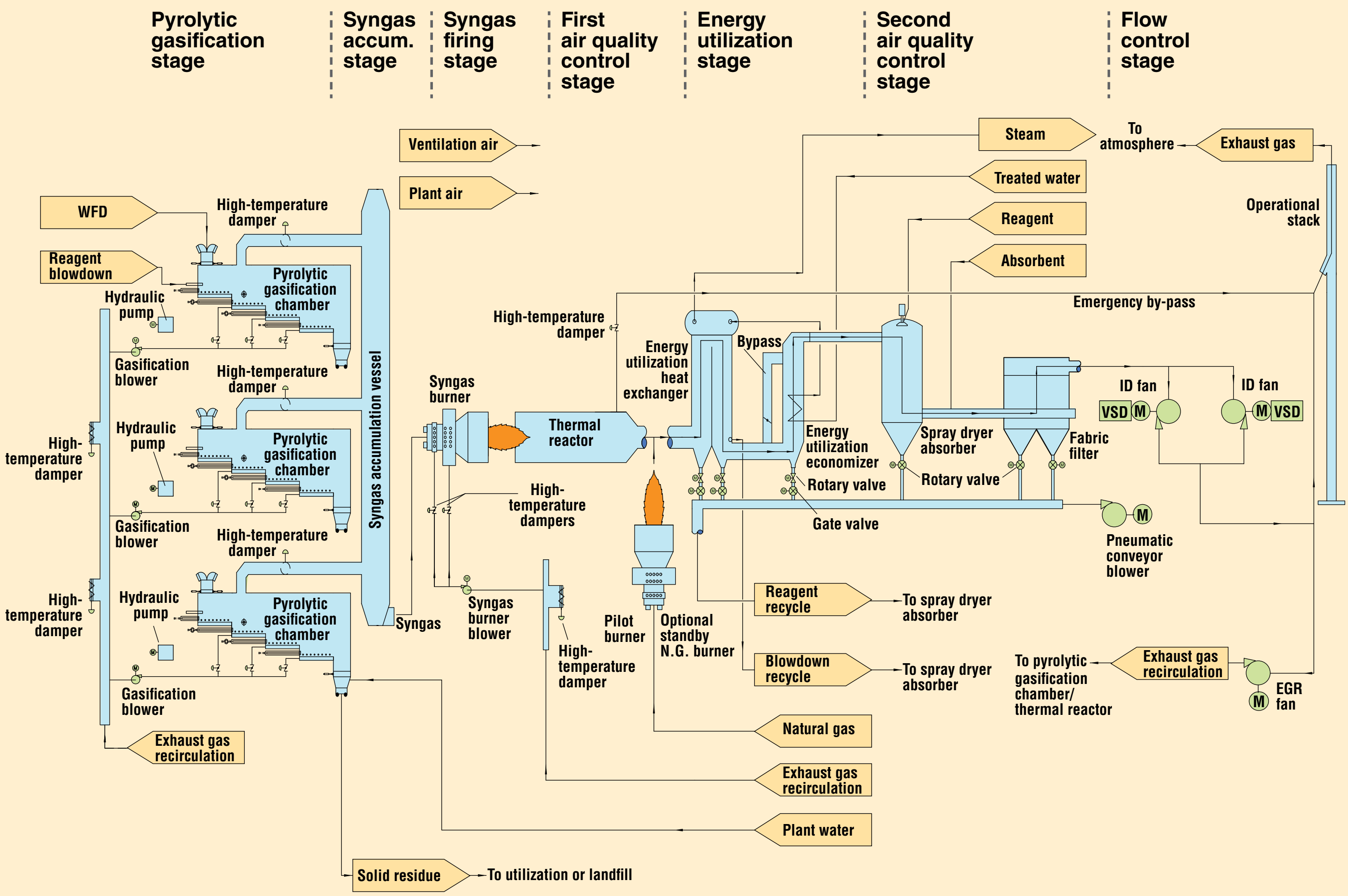
(*Continued from p. 13*)

be 94% carbon conversion and 2.7 times higher than the traditional acetone-butanol-ethanol (ABE) process. Theoretically, a 100% conversion is possible via ButyFix, compared to a maximum of 67% for other biofuel fermentation processes, says ITRI. The technology is protected by ten patents (four issued, six pending), and is available for licensing.

Biomass-to-rubber

Last month, Axens (www.axens.net), IFP Energies nouvellas (IFPEN; both Rueil-Malmaison, France; www.ifpenergiesnouvelles.com) and Michelin (Clermont-Ferrand, France; www.michelin.com) started an eight-year, €52-million research partnership to develop and commercialize a process to make bio-based

(*Continues on p. 16*)



New process for monoethylene glycol completes pilot stage

A new process for producing monoethylene glycol (MEG) from synthesis-gas-based feedstocks is nearing completion of extensive pilot plant operation, according to developers Eastman Chemical Co. (Kingsport, Tenn.; www.eastman.com) and Johnson Matthey Davy Technologies Ltd. (London, U.K.; www.davyprotech.com). The technology enables MEG production from a variety of raw materials, including coal, natural gas and biomass, and is based on new proprietary catalysts and process design developed by the two companies.

While details were not divulged, the two-stage, single-line process differs from other synthesis-gas-based technologies recently developed for ethylene glycol because it does not go through an oxalate intermediate, explains Bruce Gustafson, director of international ventures at Eastman Chemical.

"Our advanced technology can enable customers to be in the 1st or 2nd quartile of the cash cost curve for MEG production," Gustafson says, adding, "however, in regions offering low-cost syngas and methanol from shale gas or stranded coal or natural gas, we see our process as offering the lowest cash cost route."

MEG is a key industrial chemical and building block in the production of polyesters for fiber and packaging applications. Eastman says the technology is available for licensing, and dialogue is underway for the first demonstration.

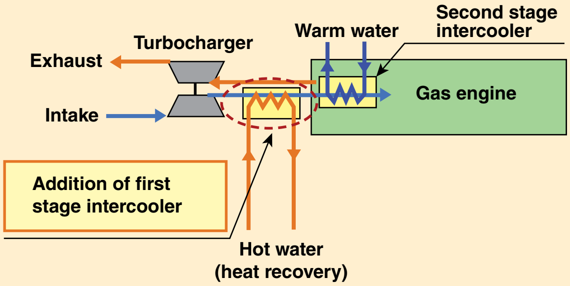
Making biogas from waste with a low organic content

The effluent discharged by domestic industries in Japan amounts to approximately 11.1 billion ton/yr. Most of this waste is comprised of relatively low concentrations of organic matter. Today, most of this effluent is treated by aerobic biotreatment (activated sludge). However, activated sludge treatment not only consumes large amounts of electric power needed to run blowers or fans, but it also produces large volumes of sludge. Now, an anaerobic fermentation process developed by Sumitomo Heavy Industries, Ltd. (SHI; Tokyo; www.shi.co.jp), in collaboration with the National Institute for Environmental Studies (NIES: Tsukuba City, both Japan; www.nies.go.jp), promises to not only reduce the volume of sludge produced, but to save up to 75% of the energy needed for the treatment.

Conventional biogas fermentation treatment can only be applied to effluent containing organic matter at concentrations of 2 to 20 grams CODCr/L (chemical oxygen demand, dichromate) and only at temperatures between 35 and 37°C. The new technology uses a specific bacteria that is capable of processing effluent containing organic matter at concentrations of about 0.3 to 1 g CODCr/L — typical of most effluent generated today — and also at ambient temperatures (10–25°C). The anaerobic digestion does not require aeration, eliminating the associated energy needed to run blowers used in the activated sludge method, so energy consumption is expected to be reduced by about 75%, says SHI.

The companies say the practical implementation of the new process is expected to be achieved within one to two years, at the earliest.

A new gas-engine cogeneration system



Last month, Mitsubishi Heavy Industries, Ltd. (MHI; www.mhi.co.jp) and Tokyo Gas Co. (both Tokyo, Japan; www.tokyo-gas.co.jop) began marketing a jointly developed 1,000-kW gas-engine cogeneration system. Based on the conventional 930-kW system, the new system's engine operates at a reduced speed (1,000 rpm instead of 1,500 rpm), so the wear-rate of components is reduced. This leads to a reduction of the overall maintenance costs by 30%, says MHI.

The engine is able to generate a higher output at lower speeds because its piston stroke has been extended by approximately 20% compared to the conventional system. Also, the use of a highly efficient turbocharger has increased the amount of compressed fuel-air mixture supplied into the cylinders, which raises the mean effective pressure by 30% from the conventional system.

The new system also features an upgraded engine-control unit that leads to a generating efficiency of 42.3%, which is said to be the highest level in the 1,000-kW class. The thermal efficiency has also been improved by upgrading the one-stage intercooler used on the conventional system to a two-stage intercooler system (diagram) to achieve an overall efficiency of 78.5%.

The combination of reduced maintenance costs and improved generating and overall efficiency leads to a considerable reduction in operating costs, says MHI. As a result, the investment costs can be recovered three years sooner than for the conventional system, the company adds. ■

(Continued from p. 14)

butadiene. The so-called BioButterfly process involves the fermentation of biomass-based feedstocks into alcohols, followed by catalytic conversion to butadiene, which is then polymerized into synthetic rubber. The project aims to develop an alternative route for elastomers.

Gasification demo

Last month, Wison Engineering Services Co. (Shanghai, China; www.wison.com) announced the startup of the Shell-Wison Hybrid Gasification Demonstration Plant, located in Nanjing, China. The new hybrid gasifier technology was developed using Shell's coal and residue gasification technologies, and is said to offer a more compact design based on water-quench technology. (For more on this topic, see "Innovations in Gasification" on pp. 24–30). ❑

FEELING THE 'BRUNT OF PROSPERITY' ON CPI WORKFORCE ISSUES

Natural-gas-related capacity expansions make workforce issues acute, but successful strategies are emerging

FIGURE 1. What sector of the CPI do you identify most closely with?

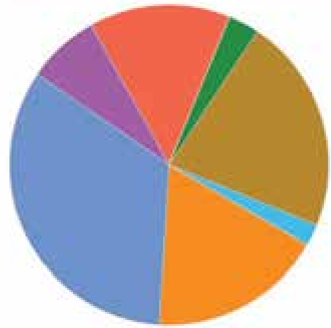
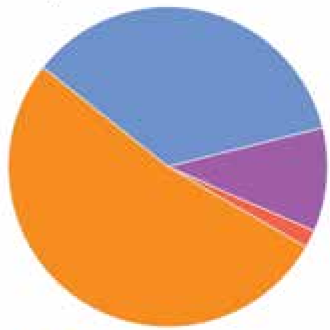


FIGURE 2. What is the highest level of post-secondary education that you have received?



FIGURES 1–6. A partial profile of the respondents in the 2013 *CE* salary survey

While staffing issues continue to be a tremendous challenge for companies in the chemical process industries (CPI), a number of strategies and training approaches are emerging to help address the need for trained engineers and skilled tradespersons.

The shale-gas boom continues to be a dominant force in the U.S. and global chemical industry, and is having a profound effect on workforce issues in the CPI. As companies seek to capitalize on the improved competitiveness allowed by the increased supply of low-cost natural gas, as much as $82.4 billion in new chemical manufacturing capacity could be invested in the U.S. by 2020, according to studies by the American Chemistry Council (ACC; Washington, D.C.; www.americanchemistry.com). Almost $72 billion in capacity-expansion investments have already been announced, mostly to expand capacity for ethylene and ethylene derivatives, as well as ammonia, methanol and propylene (see *Chem. Eng.*, October 2012, pp. 17–19). ACC estimates chemical companies will fill 46,000 permanent positions because of those investments. The reinvigoration of the CPI provided by shale gas is increasing demand for engineers, process operators, construction workers, skilled trades workers and others.

The higher demand is driving salaries up in the CPI and keeping unemployment rates minuscule for chemical engineers and CPI workers (see sidebar, p. 21). In the areas most affected by the shale-gas boom, such as the U.S. Gulf Coast, "We're really feeling the brunt of prosperity," remarks Kathleen Knolle, human resource manager at TDS (Houston; www.tdshou.com), a workforce development firm whose wide-ranging client base includes chemical plants and global Fortune 500 companies.

Intense competition

The environment of growth and expansion creates a challenge for companies trying to staff projects and new process plants, but can be an opportunity for individuals with chemical manufacturing experience.

"The competition for talent is intense, and that is driving up salaries and compensation packages," says Pat Ropella, CEO and chairman of the Ropella Group (Milton, Fla.; www.ropella.com), an executive search firm with considerable experience in the chemical industry. John Kalusa, senior talent acquisition partner for Axiall Corp. (Atlanta, Ga.; www.axiall.com) agrees: "It's a highly competitive hiring climate for engineers in chemical manufacturing; it's similar to the high-tech boom in the 1990s."

"In some areas, it's a candidate's market right now," Ropella says, especially in "hot" segments, such as the natural gas market. "And that is true for both the hydraulic fracturing side and the refining side," he adds.

A sizeable portion of shale-related jobs are located near prominent shale deposits and oilfields, Ropella adds. For example, the Philadelphia area for the Marcellus shale formation, North Dakota for the Bakken formation, Ropella says, and an emerging area will be California, where the Monterey Shale deposit is the next likely frontier in the shale sweepstakes.

Natural gas is driving companies to seek workers with oilfield production experience, and is placing a premium on hydraulic fracturing experience, including engineers with expertise in polymer chemistry, Ropella explains, because the field of polymer-coated proppants for fracturing is expanding

FIGURE 3. Which of the following best describes your employer?

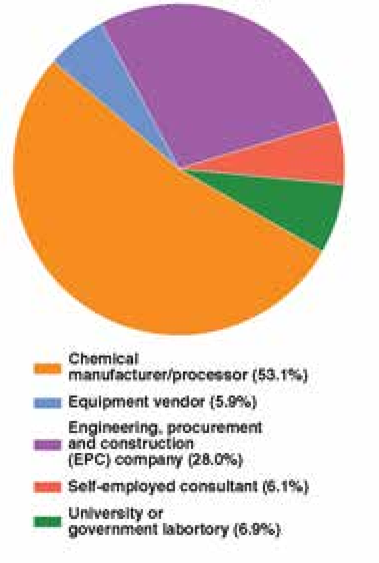


FIGURE 5. Which of the following best describes your area of work?

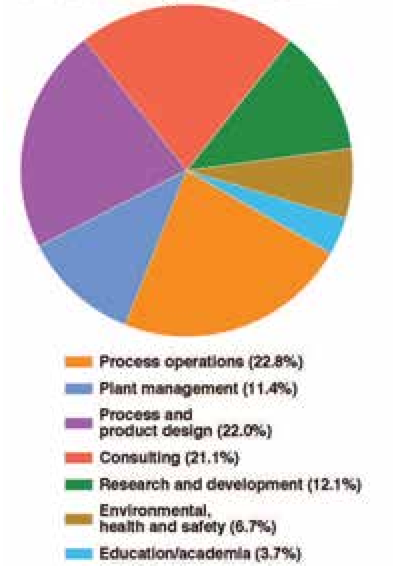


FIGURE 4. In which region of the world do you live?

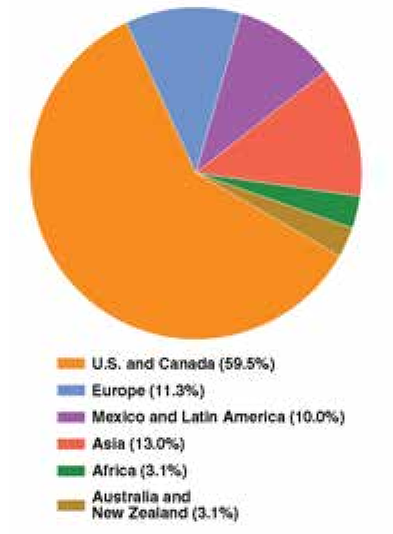
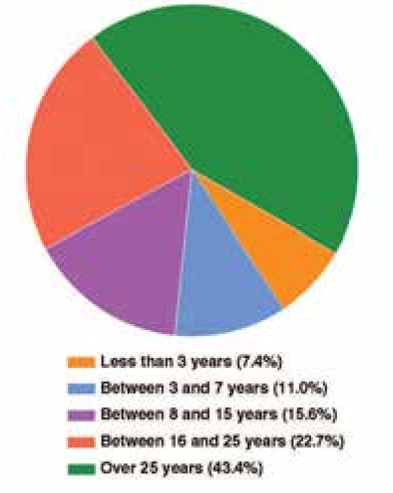


FIGURE 6. How many years of work experience do you have?



quickly. The areas of refining catalysts and water treatment are other hot areas for hiring, he says.

More broadly, demand is growing for process engineers, reliability engineers and those with facility startup experience, Axiall's Kalusa says.

Demographic complications

Paralleling the push on the part of chemical companies to recruit and hire new employees to operate new plant capacity is a demographic shift — the continuing retirement of experienced engineers of the "Baby Boom Generation" (see *Chem. Eng.*, November 2012, pp. 17–19).

"The full force of the retirement wave hasn't hit yet, but company managers are aware that it is coming," says Adam Krueger, technical recruiter with Sun Recruiting Inc. (Glen Ellyn, Ill.; www.sunrecruiting.com), a search firm focusing on chemical engineering. Executive-search consultant Pat Ropella says the improving economy is accelerating the retirement wave of baby boomers, "and that's creating succession-planning issues for companies." As younger employees get promoted, generational differences in work habits and work ethic are becoming more significant issues, Ropella says.

Strategies for solutions

"It's probably too soon to create a definitive 'best-practices' map for how to deal with these complex workforce issues," says Axiall's Kalusa, but a number of strategies and approaches that companies are utilizing are having some success.

One area that is receiving renewed attention is university recruiting. Adam Krueger, of Sun Recruiting, says that since most companies are well aware of the tight labor market for chemical engineers, they are extending college recruitment deeper into the college ranks to underclassman, rather than just graduating seniors. For companies like Axiall, college recruiting represents a longterm perspective. "We focus a great deal on college recruiting and also on running a program of structured internships for students," Kalusa says.

Aside from students, companies are also looking for other talent pools to fill their ranks. For example, Axiall puts substantial effort into leveraging military talent by matching returning veterans with technical experience with job openings where those skills are required.

The tight labor market has also made companies' abilities to develop, manage and train their own workforce more important. "A big trend right now in talent acquisition is for more focus on what we call 'candidate relationship management,'" Kalusa says. The idea is to think carefully about the longterm development of employees as a method to reduce turnover.

Training surge

The need to hire new employees, and promote others to replace retiring engineers has placed an even greater emphasis on training programs and knowledge transfer. The anticipated surge of new chemical employees will dramatically increase the need for training programs, says Robin Knowles, CEO and president of the workforce development firm TDS.

As hiring takes off, Knowles points

WHAT THE SURVEYS SAY ABOUT SALARIES

Various pieces of recent salary data seem to support the notion that competition for workers and low unemployment in the CPI is driving salaries up. Recruiters like Adam Kreuger say they are seeing "modest increases" in salaries, especially for experienced positions. Company talent managers like Axiall's John Kalusa estimate that salary expectations have risen by 10% or more over the past two years in the current CPI employment environment.

Results of an online survey conducted by *Chemical Engineering* magazine seem to support that assertion. The average salary reported by over 1,500 *Chemical Engineering* readers was $104,000, up by 14% from a similar salary survey conducted in late 2011. The median salary was $100,000. In the present *CE* survey, 49.7% of all respondents from all geographic regions reported a salary of $100,000/yr or higher, and 6.5% reported salaries greater than $200,000/yr. Respondents in the U.S. and Canada reported the highest salaries by geographic region. The average salary for respondents from those countries was $123,000, and the median salary was $113,000. The average salary for U.S. and Canadian respondents was approximately 30% higher than the average for European respondents, and about 50% higher than the average for Asia, although the sample sizes in the latter two regions were smaller.

A partial profile of *CE* survey respondents can be found in Figures 1–6. The majority (nearly 60%) of survey respondents are from the U.S. or Canada and the most commonly reported industry sector is chemicals and petrochemicals (just over one-third of respondents identified themselves as affiliated with this sector). If respondents in the chemicals and petrochemicals sector are combined with those from the petroleum-refining sector, the total would account for over half of the survey takers. The population of respondents to this survey tended to be highly experienced, with over 65% reporting 16 or more years of work experience, and highly educated. Just over 52% reported having earned a bachelor's degree, while 35% hold a master's degree and 10.5% hold a doctoral degree.

Process operations was the most commmonly reported area of work for this survey, followed closely by process and product design, and consulting. Over half of the respondents reported being employed by a chemical manufacturing company, and more than one quarter work for an engineering, procurement and construction (EPC) company.

On the other end, the number of respondents reporting no salary was approximately 1%, which would seem to be consistent with the low rates of unemployment observed in other data sources and through anecdotal evidence. Since not all respondents specified whether they were unemployed (seeking a job) or retired (no longer in the workforce), it was not possible to establish a true rate of unemployment.

Aside from the *CE* salary survey, a number of other surveys have been conducted recently on related, but different populations, and they can also provide insight. For example, according to survey results published in the June issue of *Chemical Engineering Progress*, the median salary for respondents, who are members of AIChE (American Institute of Chemical Engineers; New York; www.aiche.org), was $120,000, up 9% over a similar survey from 2011. Salary data reported in *Chemical & Engineering News* suggest that the median base salary for industry chemists is $106,600. Data from 2012 reported by the U.S. Bureau of Labor Statistics (BLS) say the average salary was $102,270 during that timeframe. New data from BLS are expected to be published next year. ❑

to two major challenges that companies will grapple with: the effectiveness and efficiency of training. "Are you seeing better performance; are you seeing behaviors change as a result of the training?" Knowles asks, and also, "how long does it take to develop people, since companies need to get newer employees up to speed faster than in the past?"

To address those dual challenges, a number of principles are emerging as critical components to training today's workforce. "Having a defined structure in the training is important," Knowles notes. "A lot of existing training approaches are haphazard and lack flow." Knowles says a plan for the training should be established upfront, so that the goal of the training is clear, and it can be designed for that purpose from the beginning.

Slade Syrdahl, senior consultant at KBC Advanced Technologies (Houston; www.kbcat.com), agrees with the need for focused, structured training, and adds that training programs best increase retention if they incorporate an element of self-direction. "The trainee needs to take more responsibility for his or her own training," Syrdahl says. His company, KBC, provides consulting and software services to the CPI and energy industry and has developed a training system for accelerated competency development that utilizes these principles. Training programs are most effective when the learner is an active participant, Syrdahl says.

With self-discovery exercises that can be thought of as guided research papers, trainees learn to ask more intelligent questions, which then enriches the time they spend with more experienced workers in their plant, Syrdahl explains. Also, when trainees go through structured tabletop drills tied to equipment troubleshooting, for example, they will receive a framework for making the most use of plant "war stories," — those experiences related by older workers to teach lessons.

The ultimate goal of active, self-directed training is to help build a richer, more robust learning culture at a facility, TDS' Knowles says. That type of culture fosters a deeper understanding of the relationships that each job function has to others. That is, "How does what you are doing affect other systems?" she adds.

Ryan Jensen, senior performance consultant at TDS, says, "We try to develop critical thinking and decision-making skills that are based on a set of more basic fundamental knowledge: we want them to understand the 'whys' more quickly, rather than just the 'whats' and 'hows.'"

Another critical element of training systems cited by Jensen is implementing performance-support tools. "Our mantra is 'improve performance,' so we want to provide tools to help people do their job better," Jensen says, "we try to use the modern electronics and IT infrastructure to embed systems and tools into the job function, so that information is easily accessible at a time and place where workers need it, in the context of their day-to-day job."

Further, Jensen says, the training material is developed into modules that can be used as needed for a particular situation.

Return on investment for dollars spent on training programs is not always appreciated in straight, bottom-line kind of business metrics, Knowles points out, but training represents a sound investment if its impact on safety is considered, says Knowles. Training can help avoid accidents that risk lives and cost millions or billions of dollars.

Company investment

To cope with the competitive labor market, companies are investing in workforce training programs, partnerships and hiring initiatives.

For example, ExxonMobil (Dallas, Tex.; www.exxonmobil.com) will fund a $500,000 workforce-training program to enable Houston's leading community colleges to prepare thousands of local residents for jobs in the growing local chemical manufacturing industry. The initiative will benefit 50,000 students and educators over the next five years. ExxonMobil has contributed more than $2.6 million over the last 10 years to manufacturing workforce training initiatives across the U.S. Gulf Coast. ■

Scott Jenkins

Siemens Fuel Gasification Technology, Energy Sector

INNOVATIONS IN GASIFICATION

Each region and each application needs a distinct gasification technology. Fortunately the equipment is growing and changing to meet the demands

There is increasing interest in meeting the growing demand for generating power, fuels and chemicals by tapping into local resources. It not only reduces reliance on imported oil and gas, but also guarantees stable price development over the long term. One available solution, according to the experts, is the environmentally friendly gasification of carbon-containing fuels, such as coal, refinery residues, biomass or waste, into these high-grade products.

Gasification is becoming an attractive option around the globe, but each region has its unique reasons for adopting the technology. Areas such as China and the U.S. are employing gasification to produce fuels and power. "For example, the integration of entrained-flow gasification into modern, integrated gasification combined cycle (IGCC) gas-fueled power plants provides a highly efficient, low-emission, and eco-friendly means of generating electricity from many kinds of carbon-containing feedstocks," explains Anton Haberzettl, head of business development with Siemens Fuel Gasification Technology, Energy Sector (Freiberg, Germany; www.siemens.com). "Carbon dioxide separation can also be easily integrated into systems of this type so that the extracted CO_2 can be stored and used, for example, to improve the yield from oil fields. This technology is called enhanced oil recovery" (Figure 1).

Similarly, due to the inherent environmental benefits, the North American gasification market is primarily interested in gasification for the energy sector, with some exploring biomass and waste as feedstocks. "Waste management companies have begun to take equity positions in waste-gasification companies," notes Alison Kerester, executive director with the Gasification Technologies Council (GTC; Arlington, Va.; www.gasification.org). "It is an attractive option because of the reduction in landfill space and the concept of recoverable energy, represented by municipal solid waste that can't be recycled, but does contain hydrocarbons, which represent energy."

However, in other regions, such as China, India, Mongolia and Indonesia. there's great interest in large-scale industrial petroleum coke (pet coke) and coal gasification, says Kerester, with a lot of emphasis on "mega projects" for converting coal to chemicals. "This is a direct result of the price of LNG [liquefied natural gas]," notes Kerester. "These countries want to use their natural resources of coal and convert it into chemicals, fertilizers, and transportation fuels. It is not only using and taking advantage of the feedstocks that are affordably available to them, but providing economic security, as well."

"That is one of the greatest benefits of gasification," notes Juhani Isaksson, manager, gasifier and pyrolysis systems with Metso (Vassa, Finland; www.metso.com). "It provides different options and possibilities based upon the feedstocks that are available and which end product, be it transportation fuels, power or chemicals, are needed in the local region. Gasification has a lot of possibilities and people all across the world are exploring its potential."

FIGURE 1. The Siemens coal gasifiers, which are 18-m long, 3-m I.D. and weigh 220 metric tons (m.t.), are among the world's largest and most powerful. They are capable of gasifying up to 2,000 m.t./d of coal. The photo shows a cross section through the reactor of a coal gasifier

How gasification works

Gasification is actually a chemical process that converts carbon-containing materials, such as coal, pet coke, biomass or other wastes, into a syngas, which can be used in the production of chemicals, fertilizers, substitute natural gas, hydrogen, and transportation fuels.

At the heart of the gasification system is the gasifier itself, a vessel where the feedstock reacts with oxygen (or air) at high temperatures. According to the GTC, there are several basic gasifier designs, differentiated by the use of wet or dry feed, the use of air or oxygen, the reactor's flow direction and the syngas cooling process.

After solid waste is ground into very small particles (liquid or gas feedstocks are fed directly), the feedstock is injected into the gasifier, along with a controlled amount of oxygen or air. Temperatures in the gasifier range from 1,000 to 3,000°F to break apart the chemical bonds of the feedstock and form syngas.

The syngas consists primarily of H_2 and CO and smaller quantities of methane, CO_2, hydrogen sulfide and water vapor. The ratio of CO to H_2 depends in part upon the type of gasifier used, but can be adjusted down-





GASIFICATION BY THE NUMBERS

The State of the Gasification Industry – the Updated Worldwide Gasification Database, a report, was prepared and presented by Chris Higman of Higman Consulting GmbH (Schwalback, Germany) at the Gasification Technologies Conference, which was sponsored by the Gasification Technologies Council, in Colorado Springs, Colo., this October.

According to the most recent figures, the database now includes a total of 747 gasification projects, consisting of 1,741 gasifiers (excluding spares), of which 234 projects with 618 gasifiers are active, commercially operating projects. The database includes 61 projects with 202 gasifiers under construction and a further 98 projects with 550 gasifiers in the planning phase. The last report was published in 2010 and covered 463 total gasification projects with 990 gasifiers.

The report attributes growth to the following three factors:

- Chinese projects
- Biomass and waste plants in Europe and the U.S.
- Updating the status of existing entries

Worldwide capacity and growth

In 2010 the gasification operating capacity was 70,000 MW_{th} syngas. According to the report, this has now grown to about 100,000 MW_{th}. Though this is close to the figure projected in the 2010 report, data behind the current figures are different. In 2010 considerable growth was predicted in the power sector, primarily in the U.S. But, in actuality, the growth has been in chemicals, mainly in China.

Gasification by location. The report states that in 2010 there had been a balanced situation between Asia/Australia, Africa/Middle East and North America. The Asia/Australia capacity, either operational or under construction, is now more than the rest of the world put together. This is mostly in China, though there is significant operating or planned capacity in India, Malaysia, Japan and South Korea. The next highest-capacity countries worldwide by syngas production are South Africa and Qatar with their Fischer-Tropsch units.

Gasification by application. Chemicals production remains the most important application of gasification. According to the report, a recent study determined that about 25% of the world's ammonia and over 30% of world's methanol are now produced by gasification. This compares with figures of about 10% in each case about ten years ago. These two chemicals remain the largest applications for gasification, though much of the methanol does not enter the market as such. Many of the larger methanol plants are captive units feeding derivatives manufacturing, such as acetyls or olefins on the same site. The report suggests an interesting new chemical application is syngas-to-glycol, with a number of plants under construction or just entering production. Syngas-to-ethanol is another chemical application that appears to have a promising future.

Synthetic fuels, both liquid and gaseous, are becoming increasingly important. The operating liquid fuels capacity is dominated by two plants: Sasol in South Africa and Pearl in Qatar. The power industry has disappointed, notes the report, compared with the 2010 projections. Many of the power projects were in the U.S., where the advent of shale gas changed the market. Also, the fact that the anticipated CO_2 legislation failed to materialize in many countries has been a factor for the power sector.

Gasification by primary feedstock. There had been a time when the use of coal and oil as a gasification feedstock was of the same order of magnitude. However, with the rising price of crude oil, coal has started to dominate the feedstock market, notes the report. There are a number of oil gasifiers among those that have been shutdown since the first issue of the database in 1999. In many cases, it is no longer economical to use oil products as a feedstock for ammonia. Coal is now the dominant feedstock and will continue to be so.

There is only a small capacity for plants that were designed for petroleum coke feed. And, biomass and waste gasification projects tend to be small because of the high cost of bringing a large amount of biomass to a single point of use.

Report conclusions

Gasification capacity continues to grow on a worldwide basis. While the majority of this growth is in Chinese coal-to-chemicals plants, other markets are also developing. The development of mega-plants, particularly for such products as Fischer-Tropsch liquids, substitute natural gas, and methanol-to-olefins, will have an impact. Large petroleum refineries are also an important influence on the growth of gasification capacity worldwide.

Excerpts of the report appear courtesy of the Gasification Technologies Council. The report in its entirety can be found at: www.gasification.org/database1/search.aspx. ❑

stream of the gasifier via the use of catalysts. The CO-to-H_2 ratio is important in determining the type of product to be manufactured. According to the GTC, a refinery would use a syngas consisting primarily of H_2, which is important in the production of transportation fuels. However, a chemical plant uses syngas with roughly equal proportions of H_2 and CO, the basic building blocks for a range of products.

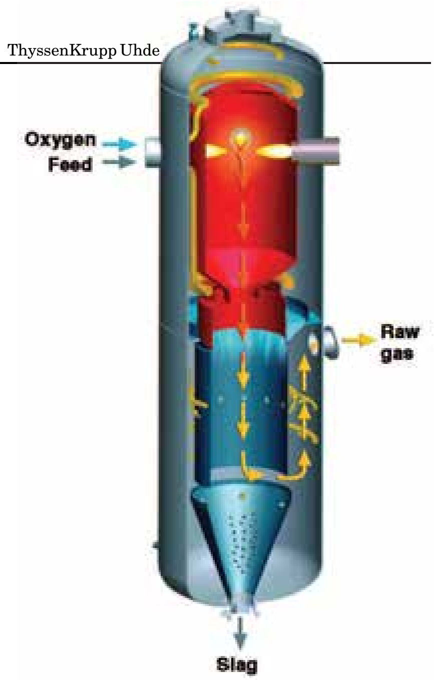


FIGURE 2. The Prenflo PDQ entrained-flow gasifier includes water quench for H_2-rich gases

This flexibility of the gasification process means that it can produce one or more products from the same process. Typically, according to the GTC, 70 to 85% of the carbon in the feedstock is converted into the syngas.

Gasification innovations

Gasification is a viable, commercially proven technology that has been around since the beginning of the last century, and hundreds of gasifiers have been operated successfully over the decades, says Claudio Marsico, head of the sales department, Gas Technologies Division of ThyssenKrupp Uhde GmbH (Dortmund, Germany; www.thyssenkrupp-uhde.eu). "Although the investment cost for gasification-based projects is relatively high, it provides significant benefits during operation," he says. "Modern gasification technologies should use the entire range of solid feedstocks, including high-ash and low-rank coal, allow a mixture of different feedstocks, avoid coal washing, use coal fines, reduce higher hydrocarbons in raw syngas, and allow maximum capacity per single gasifier to reduce investment costs and operational costs as well.

"Moreover," continues Marsico, "the design of a modern gasification plant should take into special consideration the feedstock characteristics, the final product specification, and the integration into the entire facility."

ThyssenKrupp Uhde offers several modern gasifiers to fulfill these demands. Of note is the HTW fluidized-bed gasifier that is used for high-reactive feedstocks, such as biomass, and low-rank coals with high ash-melting points. Another is the Prenflo entrained-flow process, which is available with a full water-quench design to produce H_2-rich gases or with a heat recovery system to produce CO-rich gases and steam (Figures 2 and 3).

ThyssenKrupp isn't the only company making technological improvements to the gasification system. As a matter of fact, GTC's Kerester says there are "constant innovations in the form of everything from microwave gasification to solar-assisted gasification to compact gasification to improvements in system components, such as feed injectors and refractory linings, to improvements in carbon-capture and efforts to improve gasifier performance. Now that the technology is commercially proven, every aspect of the gasification system is subject to additional R&D."

ThyssenKrupp Uhde

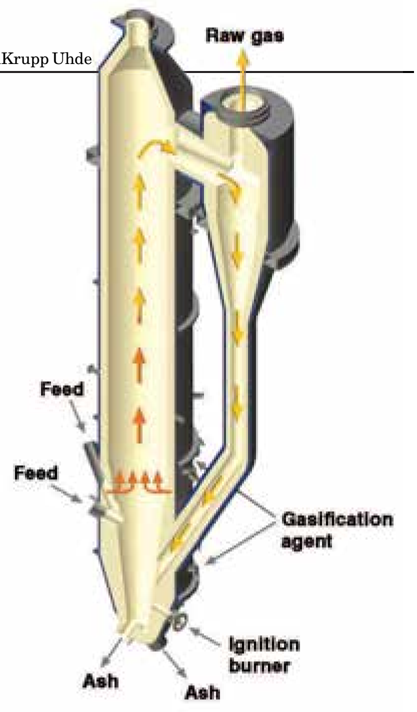


FIGURE 3. The HTW fluidized-bed gasifier is used for high-reactive feedstocks, such as biomass, and low-rank coals with high ash-melting points

As a result, there are some notable innovations. GE (Schenectady, N.Y.; www.ge-energy.com), for example, offers improved Radiant Syngas Cooler (RSC), extended slurry, and advanced refractory technologies. The RSC heat-recovery system captures heat in the form of steam during the gasification process, which converts coal to syngas. The steam production greatly reduces the need for additional steam or power produced from stand-alone boilers, boosting the efficiency and reducing the emissions of coal-to-chemical facilities, says Delome Fair, general manager of the gasification business at GE Power & Water.

GE is also introducing technology to increase slurry concentration above those obtained by traditional methods, enabling economical gasification of a wider envelope of coals. And a new refractory lining system for the gasifier vessel extends the operating lifecycle and overall availability of the gasifier, while re-

ducing maintenance costs compared to standard commercially available refractory technology, says Fair. "For example, GE's advanced refractory lining system on a U.S. IGCC plant is expected to perform 50% longer than GE's standard refractory technology, delivering one percentage point improvement to the overall plant availability," she says.

Another company is getting significant attention for its compact gasifier technology. Aerojet Rocketdyne's compact gasifier is touted as being 90% smaller and 35% more efficient than conventional gasification systems, leading to reduced costs.

"Based upon our experience in rocket propulsion systems, we have the background to handle high temperatures and high pressures in a small environment," says Alan Darby, program manager for gasification with Aerojet Rocketdyne (Sacramento, Calif.; www.rocket.com). "We began working on gasification in the 1970s and 1980s when the [U.S.] Dept. of Energy was funding coal gasification projects, but stopped the work because the price of oil dropped and the market wasn't viable for gasification again until the 2000s when the price of oil went back up," he says.

"It is our rocket engine experience that differentiates us," explains Darby. "Our gasifier is about one-tenth the size of the commercial equivalent. And because of that smaller size, when put into the gasification island, we provide an overall capital cost reduction of about 20% for the owner of the plant in the form of reduced infrastructure, concrete and other items that would go into the plant. In addition, because of the small size, the gasifier is very efficient and provides three or four points of better efficiency than commercial gasifiers, which reduces the cost of the product by 20% because it uses less oxygen for a comparative amount of feedstock. In addition, the higher efficiency generates less CO_2, so downstream equipment can also be smaller in size. All this comes together to offer a cost advantage to the plant owner."

When considering gasification, there's a lot of decisions to make, says Bruce Bryan, director, gasification with the Gas Technology Institute. (GTI; Des Plaines, Ill.; www.gastechnology.org). "There will always be much discussion as to which type, which technology, and which innovation is the best, but the point is that there is a place for all of them where it's economically feasible, and the innovations that result from mature technologies will continue to make gasification even more economic, as will local circumstances," says Bryan. ■

Joy LePree

More on global gasification projects is available online at www.che.com.

Flowmeters


ABB Measurement Products

Communicate with iOS devices with this new app

Introduced in September, the Sitrans Connection Apple iOS communication application (photo) is designed for all Sitrans F US clamp-on ultrasonic flowmeters. The Sitrans Connection enables direct communication between an Apple iOS device (iPhone, iPad or iPod Touch) and any Sitrans F US clamp-on flowmeter to enhance all metering functionalities, including programming, operational review, data logging and download. This application features full menu visibility and a complete keypad for easier navigation and programming. — *Siemens AG, Industry Sector, Industry Automation Div., Nuremberg, Germany*
www.siemens.com

Siemens


McCrometer


Endress+Hauser

This two-wire device is simpler to install

The Proline Promag 200 electromagnetic flowmeter (photo) is a two-wire magmeter with the same measuring performance as four-wire magmeters. Installation is simpler and less costly than a four-wire device because a separate power supply is not required. Promag H200 is available in line sizes of 1/12 to 1 in. and Promag P200 is available in line sizes of ½ to 8 in. for measuring flowrates of conductive fluids with an accuracy of ±0.5% of range and repeatability of ±0.2% of range. The flowmeter operates in process temperatures from –40 to 304°F. Connections include welded, threaded, hygienic and flanged versions that meet EN/DIN PN 16–40, ASME B16.5 CI 150, CI 300 and JIS 10K and 20K process-connection pressure ratings. — *Endress+Hauser, Inc. Greenwood, Ind.*
www.us.endress.com

Compact DP flowmeter family cuts installation & maintenance

This company's family of flowmeters has been extended to include four DP (differential pressure) technologies — orifice, wedge, averaging pilot and integral orifice (photo). Each family member is a one-piece flowmeter incorporating the primary element, 3- or 5-valve instrument manifold and transmitter in a single, pressure-tested assembly. The compact construction enhances both performance and safety as it involves a minimal number of leakage points compared with the many potential sources of leaks found in a conventional, DP flow installation, says the manufacturer. The compact family close-couples the transmitter and the primary measurement device, thus eliminating the requirement for long lengths of small-bore impulse piping, reducing the risk of installation errors and of blockages within the tappings. — *ABB Measurement Products, Warminster, Pa.*
www.abb.com/measurement

A new connector quickens installation and setup

With the new Quick Connect Cable, the FPI Mag electronic flowmeter (photo) is easier to install and setup for use. The Quick Connect cabling is easy to detach, making it possible to install it before the sensor, thereby allowing completion of wiring assembly prior to sensor installation. The Quick Connect Cable for the FPI Mag flowmeter is compliant with the IEC IP68 standard, and is resistant to dust and is watertight to a depth of 1 m. The Mag flowmeter's advanced microelectrode sensor compensates for variable flow profiles, including swirl and turbulent conditions. The device has an accuracy of ±0.5% of reading from 1 to 32 ft/s, and ±1% from 0.3 to 1 ft/s. The signal converter includes built-in

Note: For more information, circle the 3-digit number on p. 68, or use the website designation.

Circle 6 on p. 68 or go to adlinks.che.com/45779-06

4–20-mA outputs and additional programmable outputs to support Scada systems. — *McCrometer, Inc., Hemet, Calif.*
www.mccrometer.com

A space-saving redesign also improves accuracy
The new IZMAG2 (photo) features a redesigned measuring tube that eliminates the need for inlet or outlet pipe sections. This saves space, making the IZMAG2 easier to position precisely into tight spaces and improves its measurement accuracy by ±0.2%. Vacuum resistance is achieved by mechanically anchoring the synthetic material to a stainless-steel lattice, which makes the device impervious to water vapor and resistant to cleaning temperatures of up to 80°C. As with previous versions, the IZMAG2 also features a visual display, 360-deg positioning and Bluetooth compatibility. — *GEA Diessel GmbH, Hildesheim, Germany*
www.gea.com

Krohne Messtechnik

GEA Diessel

Bronkhorst High-Tech

Sierra Instruments

Space- and cost-saving flow-control solution
By means of the innovative mounting concept Flow-SMS (photo), a variety of components for mass flow and pressure measurement and control can be assembled to constitute a very compact gas delivery system. On a lightweight, but still-rugged mounting rail system, one or more mass flow (or pressure) sensor and control modules can be combined with mixing chambers, (pneumatic, electrical or manual) shut-off valves, filters or any other functional module as needed. Flow ranges can be selected between approximately 5 mL/min up to 50 L/min or even higher. In case a pressure sensor or controller is included, the pressure range can be chosen between 0–100 mbar and 0–10 bars absolute or gage. — *Bronkhorst High-Tech B.V., Ruurlo, the Netherlands*
www.bronkhorst.com

A flowmeter for demanding applications
The New Optisonic 3400 ultrasonic flowmeter (photo) is a three-beam, inline device that can be used for both standard and more demanding applications, in terms of process temperature, pressure and high viscosity. This new multipurpose flowmeter offers bi-directional flow measurement independent of the medium's conductivity, temperature density and pressure. Based on the transit-time method, the device has three parallel ultrasonic beams that generate a measurement independent of flow profile, with a flow range of 0.3 to 20 m/s and accuracy of ±0.3%. The temperature range extends from –200 to 250°C, and viscosities can reach as high as 1,000 cSt. — *Krohne Messtechnik GmbH, Duisburg, Germany*
www.krohne.com

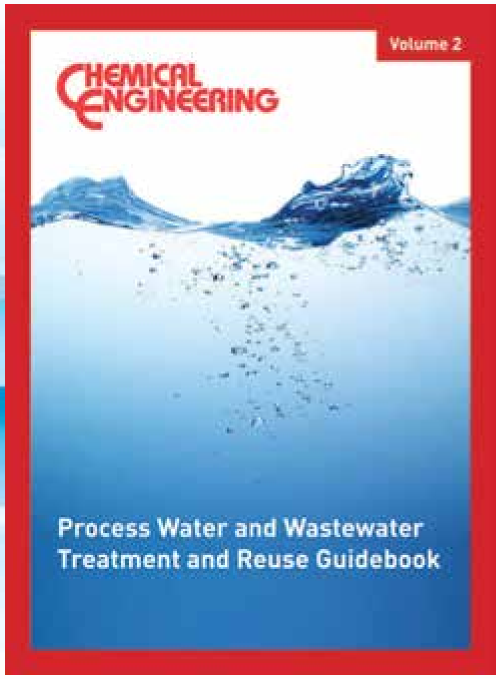
Totalizing software monetizes up to four gases
This company recently released a new free-flow totalizer software module for its QuadraTherm 640i/7800i mass flowmeter (photo). Via the QuadraTherm software interface program (SIP), users now have an efficient management tool to totalize and monetize gases with one device. The module leverages the flowmeter's high accuracy (±0.5% of full scale) to give the most accurate totalization of multiple gases. Up to four gases can be totalized from a single device and software package. — *Sierra Instruments, Monterey, Calif.*
www.sierrainstruments.com

This inline flowmeter accurately measures gases
The MTI10 Insertion and MTL10 Inline Mass Thermal Flowmeters provide accurate measurement of clean, dry gases and air using constant temperature sensing for fast response and low-flow accuracy. Additional transmitters or flow computers are not needed, and the devices are immune to changes in temperature and pressure over a wide flow range. The MTI10/MTL10 View software allows for quick setup, monitoring and data logging of the flowmeter using a PC. The Cal-V and Recalibration Verification allows users to perform in-situ testing of the meter's accuracy by testing the functionality of the sensor and the processing circuitry. — *Spirax Sarco, Inc., Blythewood, S.C.*
www.spiraxsarco.com/us ■

Gerald Ondrey

Now Available in the *Chemical Engineering* Store:

Process Water and Wastewater Treatment and Reuse Guidebook- Volume 2



This guidebook contains how-to engineering articles formerly published in *Chemical Engineering*. The articles in Volume 2 provide practical engineering recommendations for process operators faced with the challenge of treating inlet water for process use, and treating industrial wastewater to make it suitable for discharge or reuse.

There is a focus on the importance of closed-loop or zero-discharge plant design, as well as the selection, operation and maintenance of membrane-based treatment systems; treating water for use in recirculated-water cooling systems; managing water treatment to ensure trouble-free steam service; designing stripping columns for water treatment; and more.

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DECEMBER New Products

Flowserve

Chandler Engineering

Cynergy Ergonomics

Evaluate scale inhibitors with this automated system

The Model 5400 Dynamic Scale Deposition Loop (photo) is a fully automated system that measures and evaluates the performance of scale inhibitors under high-pressure and high-temperature conditions. This system pumps heated samples at controlled rates through a tubing test section, while continuously measuring the differential — an increase in differential pressure indicates scale formation. System features include a forced-air convection oven, a removable sample-tube assembly, two setpoint back-pressure regulators, and an external pH electrode. Two high-performance liquid chromatography pumps are used to transport the fluids through the tubing. The system also includes proprietary software that collects, calculates and stores acquired data. — *Chandler Engineering, Broken Arrow, Okla.*
www.chandlereng.com

Mechanical seals that are diamond-coated for reslience

These mechanical seals feature diamond-coated faces (photo), which produces an extremely resilient surface with desirable friction and wear characteristics. Beneficial in services requiring protection from slurry, dry-running conditions or chemical corrosion, the coated seals offer improved reliability in poor-lubricity liquids, such as hot water. These seals are also suited for very aggressive liquid service, such as with acids, caustics and alkaline materials. The diamond-coated faces allow operation against all common mating-face materials including, carbon, silicon carbide and tungsten carbide, as well as providing resistance to abrasive particle damage. — *Flowserve Corp., Irving, Tex.*
www.flowserve.com

Emerson Electric

A robust vibration analyzer with ergonomics in mind

The CSI 2140 Machinery Health Analyzer (photo) is a portable tool for analyzing machinery vibration to detect potential problems before they lead to unplanned downtime. This analyzer's compatibility with the asset-management software, AMS Suite's Machinery Manager Version 5.6 allows users to perform more advanced analysis. Four-channel data collection leads to faster route completion and additional diagnostic tools, like dual-orbit plots on couplings. Users may wirelessly upload data to the software. A lithium-ion battery ensures battery life that will cover an entire shift from a single charge. The analyzer is ergonomically designed to be thin and light, intended for one-handed operation, with a shoulder strap for additional comfort. A glove-friendly touchscreen features an auto light sensor that optimizes the screen's backlight. — *Emerson Process Management, St. Louis, Mo.*
www.emersonprocess.com

A universal lifting system for material of any geometry

This company's new universal lifting system (photo) can lift and manipulate materials that have vastly different geometries with a single vacuum lifter. With a capacity of over 1,000 lb, the lifter's vacuum-maintenance design can handle cylindrical products such as pipe, flat items like boards or panels, as well as varied geometries such as turbine blades or pallets. With the ability to handle virtually any shape or geometry, this vacuum lifter is appropriate for custom manufacturers and applications that ship or receive a wide range of products. — *Cynergy Ergonomics Inc., St. Louis, Mo.*
www.cynergyergonomics.com

Note: For more information, circle the 3-digit number on p. 68, or use the website designation.

Benko Products

Griswold Pump Company

ABB Group

A touchscreen video recorder with options for data monitoring

The RVG200 (photo) is a videographic data recorder with touchscreen technology. Providing easy access to process data for onsite operators, the RVG200 also enables secure remote data access from tablets, smartphones or personal computers, for a true realtime overview of monitored processes. Integrated into the plant network through an Ethernet connection, the recorder can notify operators of process alarms or critical events, via email to their mobile device or computer. Data can be viewed in a variety of formats, including charts, bar graphs or digital indicator displays. — *ABB Group, Zurich, Switzerland*
www.abb.com

Mokon

An industrial refrigerator with built-in spill protection

The Husky Cold Box (photo) is an industrial refrigerator designed for use with 55-gal drums. With a capacity of up to 32 drums, the Husky Cold Box is forklift-portable, features built-in spill containment and 3-in. thick insulation, which minimizes power consumption when compared to a large walk-in cooler. The refrigerator's exterior is finished with acrylic enamel, while the interior is finished with silver. Stainless-steel finish is also available. The small footprint makes this refrigerator well-suited for plants with limited floor space. The Husky Cold Box comes fully assembled for quick deployment. — *Benko Products, Sheffield Village, Ohio*
www.benkoproducts.com

Administer solid water-treatment chemicals with these feeders

The Model CLR-25 and CLR-50 bromine feeders are designed to efficiently feed solid water-treatment chemicals into closed-loop systems in cooling towers. With the versatility to handle bromine in many formats including ball, stick and tablet, the CLR-25 has a total capacity of 25 lb and the CLR-50 has a capacity of 50 lb. Both models feature a clear polyvinyl chloride body so the bromine supply can be viewed without opening the cap. The feeders have a maximum pressure of 8.6 bars and a maximum temperature of 38°C, and come equipped with a standard pressure-relief valve. — *Neptune Chemical Pump Co., North Wales, Pa.*
www.neptune1.com

This heat-transfer-oil system stops leaks for less downtime

The HTF NPS Series (photo) is a new heat-transfer-oil system capable of operating at temperatures up to 204°C. The HTF NPS series provides accurate temperature control for situations that require negative pressure to stop a leak, as well as positive pressure when no leak is present. The system's three-way flow-control valve can rapidly switch from positive pressure to negative pressure. The system's leak-stoppage capabilities delay repair requirements, allowing continuous production through the end of a run. System components include a fluid-supply reservoir, a microprocessor-based controller and a vertical stainless-steel pump. — *Mokon, Buffalo, N.Y.*
www.mokon.com

Use these self-priming pumps in water service

This company's H Series of high-head self-priming centrifugal pumps (photo) are designed for a variety of water-related applications. Unlike standard end-suction centrifugal pumps, the H Series maintains its prime even if check valves or foot valves fail. The suction line's location on the pump keeps the impeller and mechanical seal covered with water at all times, protecting the seal from dry-run, and eliminating the need for re-priming. The H Series pumps are available in models ranging from 3 to 20 hp. — *Griswold Pump Company, Grand Terrace, Calif.*
www.griswoldpump.com ■

Mary Page Bailey

2013 CHEMSHOW
DEC.10-12 // NEW YORK CITY

The 2013 Chem Show (www.chemshow.com) will take place in New York on December 10–12 at the Jacob Javits Convention Center. This biennial event will showcase process equipment and technology from across the chemicals processing industries (CPI), with over 300 exhibitors expected to participate with hands-on demonstrations, seminars and new product releases. The following is a preview of some of the products and services that will be exhibited at this year's event.

Pfeiffer Vacuum

Fluid Metering

Porvair Filtration Group

These pumps are self-cooled via a recirculation process

OktaLine G Series gas-cooled pumps (photo) are suitable for harsh environments or where process gas has a narrow temperature limit. The pumps' self-cooling mechanism involves recirculation of a small amount of pumped process gas that is sent through a heat exchanger and injected back into the high-compression area inside the pump. This self-cooling process helps to extend bearing and seal lifetimes and decrease system complexity, since there are fewer pump stages. These pumps can also achieve large pressure differentials and can route exhaust directly to atmospheric pressure. Booth 551 — *Pfeiffer Vacuum GmbH, Asslar, Germany*
www.pfeiffer-vacuum.de

A 'no valve' solution for precise metering and dispensing

The PDS-100 (photo) is a valveless, programmable dispensing system, available in single- and dual-channel configurations. Ideal for accurate metering, dispensing and sampling, the system can handle liquids, slurries and gases for both laboratory and industrial applications. A chemically inert, ceramic piston is the only moving part that contacts the process fluid. Pump heads are integrally mounted to the control unit, with motors, drivers and electronics housed in a rugged aluminum enclosure. The system's menu-driven programming uses front-panel membrane switches on an LCD display. Booth 723 — *Fluid Metering, Inc., Syosset, N.Y.*
www.fluidmetering.com

These flexible filter cartridges can be treated for many applications

This company's robust new cartridges (photo) for its stainless-steel purification filters are available in all standard cartridge lengths, micron ratings and 316L stainless-steel end fittings. For further customization, other alloys and dimensional modifications are available upon request. With optional patented surface-modification treatments, the cartridges can be specially prepared for applications where additional pH or temperature protection is required. Booth 655 — *Porvair Filtration Group, Hampshire, U.K.*
www.porvairfiltration.com

This continuous-flow reactor is fully scalable

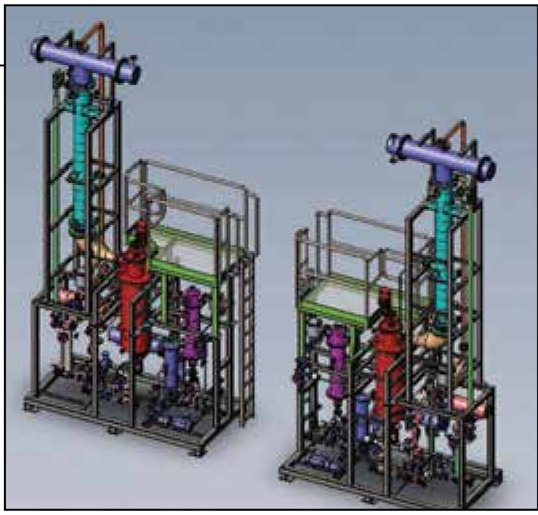
The Coflore Agitated Cell Reactor (ACR) is a continuous-flow alternative to batch processing. This fully scalable unit develops chemistry at low throughput, and provides plug flow, while eliminating back-mixing and side reactions. Mechanically stirred with a patented stirring technology, the ACR can handle slurries, immiscible fluids and gas-liquid mixtures for a wide range of reaction times. The ACR is appropriate for scaleup applications in industries such as food, biofuels, specialty chemicals, polymers and pharmaceuticals, due to its ability to produce high yield and purity with less waste. Booth 236 — *AM Technology, Cheshire, U.K.*
www.amtechuk.com

Improve evaporator performance with this rotor system

The new Powerfilm Rotor system (photo, p. 39) can improve performance and product quality for many industrial evaporators, including wiped-film, short-path and thin-

Note: For more information, circle the 3-digit number on p. 68, or use the website designation.

Houston Polytank



GIG Karasek

film, as well as vacuum-molecular distillation processes. Using a proprietary technology that optimally adjusts performance depending on a product's characteristics, this system increases process capacity and eliminates nearly all impurities, thus cutting operating costs. Booth 731 — *GIG Karasek, Gloggnitz-Stuppach, Austria*
www.gigkarasek.at

Highly customizable tanks give versatility

This company's polypropylene and polyethylene molded tanks (photo) can be produced to customer specifications, giving customers the ability to design and build a tank with the proper wall thickness for their application. Design considerations include corrosion properties, specific gravity and temperature requirements of the stored material. Built-in insulation and secondary-containment options are also available. Tank sizes can vary from 50 to 50,000 gal, with bottom configurations including flat, internal-slope or cone. NSF 61 certified, these tanks' versatility makes them appropriate for use in many industries, including chemical processing, agriculture, food products, electricity generation, medical, mining and water and wastewater applications. Booth 744 — *Houston Polytank, LLC, Hopkins, Mo.*
www.houstonpolytank.com ■

Mary Page Bailey
Edited by Mary Page Bailey

CHEMICAL ENGINEERING
FACTS AT YOUR FINGERTIPS

Department Editor: Scott Jenkins

Filtration Testing and Slurry Conditioning

Testing in filtration processes is critical for determining the properties of solids being filtered and the ease or difficulty of the filtration. In addition, laboratory testing is important in specifying filter media, filter aids, filter area, cake space needed and cake discharge techniques. Experimental data gathered in the laboratory help in the design of the full filtration system needed for production. In many cases, the optimal filtration system involves combining various filtration techniques with different configurations. The mechanical conditioning of slurries allowed by combining filtration techniques gives rise to a more efficient overall filtration process. This article discusses what data are required for slurry testing and provides examples of mechanical conditioning of slurries using combinations of filtration methods.

Test objectives

Laboratory testing often uses a test sample of process fluid in a container that allows measurement of the volume of the test batch for filtration. Tests are designed to analyze cake depths, operating pressures, filter media, washing and drying efficiencies and cake discharge. An example of a data collection sheet for filtration laboratory testing is shown in Table 1. The specific objectives may be to determine the required filter area for a primary filtration, evaluate filtrate quality for primary and secondary filtration, or evaluate washing efficiency.

Data collected during testing include the following:

- Slurry volume
- Slurry density
- Percent solids in feed
- Temperature
- Time for filtration
- Pressure or vacuum
- Pressure of wash material

Visual inspection of filtered solids can offer clues about filterability. Solids that are crystalline can be relatively easy to filter, whereas amorphous, slimy or gelatinous solids are more difficult to separate, requiring more complex techniques. In addition to the visual inspection, particle-size analysis of the suspended solids is always recommended to determine the percentage of solids and the particle-size distribution in the process. The test data will help determine the size and recommendation for the filter type.

Filter sizing

The test data are then used in the following formulas to calculate filter-sizing requirements to meet the process flowrate, batch throughput and the solids removed in the filter cake:

$$\text{Throughput} = V/A \quad (1)$$

$$\text{Flowrate} = (V/D_t)/A \quad (2)$$

$$\text{Cake thickness} = Ws/rsA \quad (3)$$

Where:
V = total volume filtered, gal
A = total filtration area, ft^2
D_t = total time to filter, min
Ws = total weight of solids filtered, lb
rs = density of wet cake, lb/ft^3

TABLE 1. DATA COLLECTION SHEET

Customer:		Test number:
Date :		Run #
	Filter media	
	Suspension	
Filling	Volume of slurry	
	Density of slurry	
	% Solids in feed	
	Temperature	
Filtration	Vacuum or pressure	
	Volume of filtrate	
	Time for filtration	
	% Solids in filtrate	
Wash 1	Wash material	
	Pressure	
	Volume of filtrate	
	Time for filtration	
Wash 2	Wash material	
	Pressure	
	Volume of filtrate	
	Time for filtration	
Drying	Pressure	
	Temperature	
	Flowrate	
	Time for drying	
	Pressing pressure	
Cake	Weight	
	Thickness	
	% Residual moisture	
	Dry cake weight	
	Cake discharge OK?	

If laboratory testing is not feasible at plant facilities, then filter equipment companies, filter aid suppliers and consultants are available to assist with testing work.

Slurry conditioning

Tests often indicate that the most effective filtration process involves two stages, where a primary filtration step occurs first, often as a continuous process, and is followed by a secondary filtration step that may be carried out as a batch process. The following are some examples of how these processes could work (Figure 1).

Continuous vacuum followed by candle filtration. In cases where high-solids slurries have a small particle size distribution, continuous vacuum filtration can be used to create a very thin cake with a thickness of 5–6 mm. High-solids slurries can be defined as up to 50–55% solids in the slurry feed. The mother filtrate often contains small, very fine solids. Using candle filters, these solids can be filtered, washed, concentrated and then sent back to the process.

Candle filtration followed by continuous vacuum filtration. If the order of the filters is reversed, the candle filters operate to mechanically condition the slurry through thickening and concentrating up to 10% solids. The resulting more-concentrated slurry can then be economically and technically processed on a vacuum belt filter by vacuum filtration, cake washing and drying. The drying can be by vacuum, compression, blowing with hot or ambient-temperature gas or by steaming. Applications for this approach occur in chemical plants as well as in coal gasification plants. Concentrating candle filters can also be followed by pressure-plate batch filtration.

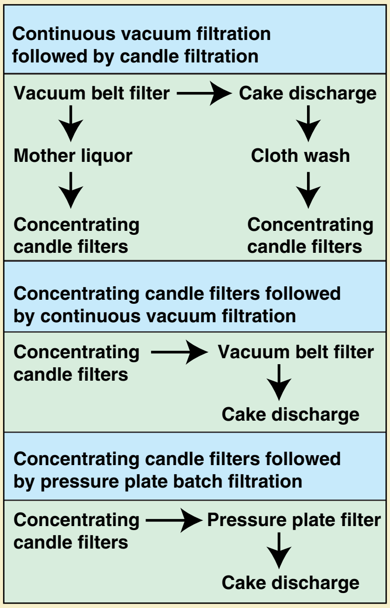


FIGURE 1. Examples of combination filtration approaches that can be used for slurry conditioning

When primary filtration is accomplished by candle filters on a continuous basis, the filter medium is capable of retaining particles down to 0.5 μm in size. These particles are discharged as a concentrated sludge or slurry onto a pressure plate filter for recovery of the remaining solvent and discharge of the dry cake. The secondary filtration is a batch process that incorporates filtration, counter-current washing, drying and dry cake discharge. The overall result is a very dependable process with high quality filtrate and minimal utility air and water usage.

Continuous pressure filtration or centrifugation followed by candle filtration. In cases where the initial mother liquor contains fines in the 1–5-μm size range, the best process decision could be to accept fines in the mother liquor, rather than having a reduced flowrate because of a tighter filter cloth. The fines would then be recovered in the candle filters, which can either produce a dry cake or concentrated slurry.

In summary, the installation and combined use of filtration technologies, while higher in capital cost, will result in a more reliable operating process at the plant. However, only through accurate laboratory and pilot testing will the optimum filter selection be realized.

Editor's note: Special thanks go to Barry Perlmutter, President of BHS-Filtration Inc. (Charlotte, N.C.; www.bhs-filtration.com) for contributing content for this column. He can be reached at barry.perlmutter@bhs-filtration.com.

References

1. Sentmanat, S., Clarifying Liquid Filtration, *Chem. Eng.*, October 2011. pp. 38–47.
2. Perlmutter, B.A., Combination filtration of pressure, vacuum and clarification technologies for optimum process solutions, BHS-Filtration Inc., Charlotte, N.C., 2012.

Butene via Ethylene Dimerization

By Intratec Solutions

Olefin dimerization is a reaction where two molecules of a monomer combine to form a dimer. It can be utilized to produce normal butenes from ethylene, which can be provided by a steam cracker.

Dimerization of ethylene is generally applied when butene is required in another part of a petrochemical complex. For instance, the dimerization unit may be integrated with a metathesis unit, to produce polymer-grade propylene, a commodity chemical with a high added value. In this integration, *n*-butene from dimerization is reacted over a metathesis catalyst with ethylene to form two molecules of propylene, as shown in the block flow diagram, in Figure 1.

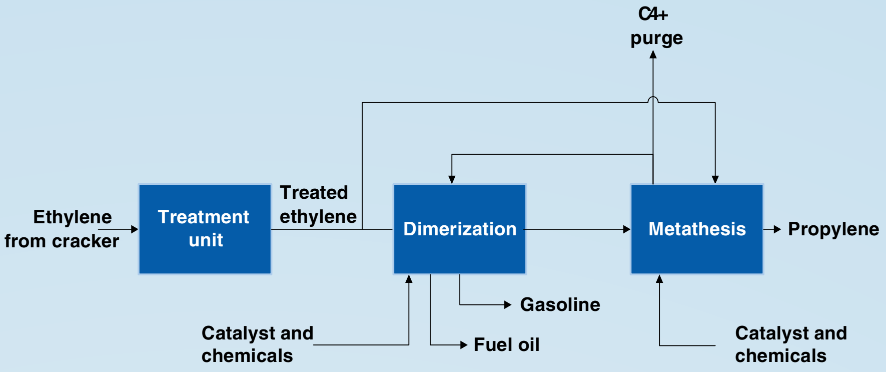


FIGURE 1. Integration between dimerization and metathesis

The process

A dimerization process for butenes production, similar to CB&I Lummus (The Woodlands, Tex.; www.cbi.com) Ethylene Dimerization Technology, is analyzed and depicted in the flowsheet (Figure 2). The following is a brief description of the dimerization processing scheme:

Catalyst preparation and treatment section. Catalyst and co-catalyst are properly unloaded, stored and pumped into the catalyst preparation section. Ethylene is treated in the purification unit, prior to mixing with the catalyst, to remove potential dimerization-catalyst poisons.

Reaction section. The reaction system produces *normal* butenes, mainly 2-butene, as the major product, with higher olefins (such as hexenes and octenes), as byproducts. The reaction occurs in a liquid-phase loop system, with a high circulation flowrate. The reaction medium — containing the catalysts, *n*-butenes and recirculated unreacted ethylene — is fed to the surge drum, which provides liquid surge to the loop. A heat exchanger, which removes the exothermic heat from the circulating liquid, acts as the dimerization reactor. After the reactor stage, part of the reaction medium is sent to the quench section while the remainder is recirculated.

Catalyst quench section. In the quench section, the catalysts are deactivated with caustic solution. Fresh caustic is added to the reaction product, after which it goes to the liquid-liquid separator drum, where the caustic is withdrawn from the bottom and purged to the flash drum prior to being recycled. The same occurs with the steam condensate, which is used to remove traces of caustic. In the flash drum, hydrocarbons in the purge stream are sent to flare, while the liquid is sent to water treatment.

Purification section. In the debutenizer tower, the overhead butenes and any unconverted ethylene are separated from heavier reaction byproducts. The bottom is sent to the heavy-ends tower, which produces gasoline as distillate and fuel oil as bottoms, while the overhead is sent to the butenes purification tower. In the butenes tower, unreacted ethylene is separated from the product and recycled to the reaction section. In case of metathesis integration, the purification tower is not utilized, since both olefins will be used as raw materials.

Total installed cost

An economic evaluation of the ISBL (inside battery limits) total installed cost, which accounts for the ethylene treatment unit and the dimerization unit, was conducted based on data from the fourth quarter of 2012, for a plant with a nominal capacity of 200,000 ton/yr of butenes erected on the U.S. Gulf Coast (the process equipment is represented in the simplified flowsheet below).

The ISBL total installed cost is about $30 million. The cost includes: the process equipment and equipment spares; housing for process units; others direct material; and indirect costs (field supervision, payroll burdens and so on).

Recently, the shift to lighter feedstocks from low-cost natural shale gas is reducing the propylene production in steam cracker units. Thus, the construction of a dimerization unit integrated to a metathesis unit can be a solution when there is an excess of ethylene production and a demand for propylene. ■

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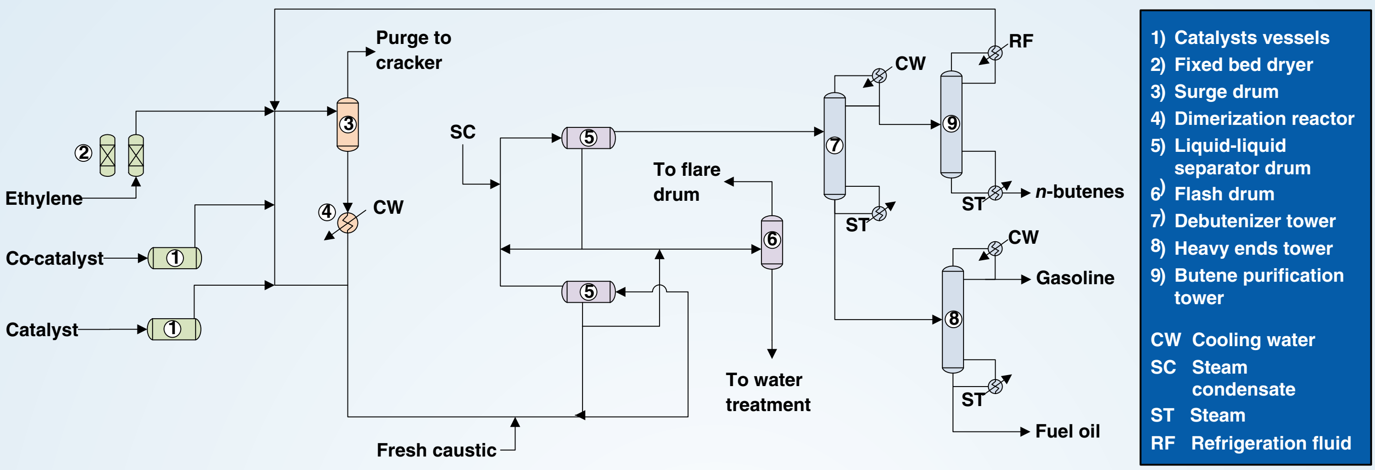

FIGURE 2. *n*-butenes production process similar to Lummus Ethylene Dimerization Technology

The Globally Harmonized System

This introduction to the Globally Harmonized System of the Classification and Labeling of Chemicals can help in understanding the new classification requirements

Paul Burgess
Labelmaster

When the U.S. Occupational Safety and Health Administration (OSHA) revised the U.S. Hazard Communication Law, U.S. 29 CFR 1910.1200, in May of 2012, it set off an avalanche of change in the environmental, health and safety (EH&S) circles of American industry. Virtually every manufacturing and service industry will be involved in one aspect or another of adapting its existing hazard communication system to the new Globally Harmonized System (GHS) for the classification and communication of chemical hazards. As you are likely aware, the law requires all affected workplaces to train their employees in the exigencies of the new hazard communication system by December 1, 2013, and ensure that their employees understand the new labeling and safety data sheets that need to be completely in place by June 1, 2016. However, the industry segments that will likely experience the greatest change are the chemical process industries (CPI).

The detailed work of compiling data for publication in the new safety data sheets, and updating labeling to comply with the new standard, is just the beginning for U.S. chemical producers. The single greatest change facing the CPI in the new system is the requirement to classify chemicals into one of the newly designated hazard categories, as well as assigning an appropriate level of risk severity for each product. This is a significant change. Previously, chemical manufacturing's primary responsibility was to evaluate hazards associated with a product, and classification was left to the transportation industry to fret over in the formal chemical identity process.

Implementation Dates

Dec. 1, 2013	June 1, 2015	Dec. 1, 2015	June 1, 2016
Employers must train employees on the new label elements and safety data sheet (SDS) format	Chemical manufacturers, importers, distributors and employers must comply with all modified provisions	Distributors begin shipping containers labeled by the chemical manufacturer or importer with an HCS label	Employees must update alternative workplace labeling and hazard communication programs as necessary and provide additional employee training for newly indentified physical or health hazards

FIGURE 1. The first deadline of effective dates for implementation of the GHS in the U.S. has been reached

Under the 2012 Hazard Communication Standard, most general industry chemical users merely need to ensure their employees' right to understand. Classifying chemicals is taken care of at a level typically above their involvement, by distributors, importers, and most especially by manufacturers. Downstream users are only required to reclassify their chemicals from the original classification if, and only if, they modify the chemicals to such a degree that they can reasonably expect that the product's hazards have changed. While certainly not an unheard of circumstance, it is a relatively rare one.

Thus, while distributors and importers of chemicals may have some role to play, the burden of classification will fall mostly into the hands of the manufacturer. By the nature of their operations, manufacturers possess an adequate staff of technical experts to safely create the chemicals that they market. Such staff usually also includes the resources that will now be required to ensure proper classification according to the GHS-based hazard communication system.

The path to the GHS

Prior to 1970, worker protection laws in the U.S. were a hodgepodge. A variety of state and federal rules created a widely disparate set of circumstances under which employees might find themselves working and experiencing risk. In 1970, the Federal Government created OSHA. OSHA's mandate was to make the labor safety laws in the U. S. com-

GHS hazard classifications

Physical hazards	Health/environmental
• Explosives	• Acute toxicity
• Flammable gases, aerosols, liquids, solids	• Aspiration
• Oxidizers	• Skin corrosion and irritation
• Self-reactors	• Respiratory and/or skin sensitization
• Self-heaters	• Mutagenicity
• Pyrophorics	• Carcinogenicity
• Organic peroxides	• Reproductive damage
• Corrosives	• Organ toxicity, single and multiple doses
• Pressurized gases	• Danger to aquatic environment
• Dangerous when wet	

FIGURE 2. The new rule sets very specific guidance, which must be followed, to classify chemical hazards

mon, and to impose at least a minimum standard of acceptable safety and risk management throughout American industry. Though not without some controversy, the agency has generally been highly successful at the task of improving workplace safety conditions and worker health.

Today, American labor benefits from one of the highest rates of employee hours worked per reportable injury of any developed nation. OSHA is also generally seen as being reasonably responsive to the needs of industry — a careful balancing act that has seen it weather administrations that cross the political spectrum. Among OSHA's many other achievements, it promulgated the first version of the Hazard Communication Standard (HCS) in 1983. This required employers to train employees to recognize the chemicals that they used or were routinely exposed to in their workplace, as well as the associated risks the chemicals presented. It also required the maintenance of accurate inventory data for chemicals present on the site, and specified the availability of material safety data sheets, or MSDSs, for each chemical.

While a variety of minor changes ensued over the next three decades, in general, the rule remained more-or-less as it was written. HCS warning systems based on the familiar National Fire Protection Association (NFPA) System Type 704 four-color diamond, and the broadly similar (though differently shaped) HMIS (Hazardous Material Identification System) warning system, as well as other products, were developed and deployed on a national, and in some cases, global basis. Many places in the world followed the U.S. lead in developing their own hazard communication requirements. However, in 2009, a change to the law was proposed based on the rapidly burgeoning, United Nations-sponsored Globally Harmonized System of the Classification and Labeling of Chemicals, or GHS.

In 1992, hazard communication experts from around the world gathered in Rio de Janeiro, Brazil under the auspices of the United Nations to define a new globally acceptable format for hazard classification and warning for the workplace. The goal was to eventually replace the many disparate systems in use with one, globally recognized and understandable system that would supersede all existing systems and allow the easy, routine transfer of chemicals from one place to another with worker recognition and safety in mind. Pictograms would identify major risk categories, and standardized language and commonly accepted criteria would be used to classify chemicals for their attendant hazards, as well as to explicate the risks involved with their use and handling. Thus was born the GHS.

In 1992, it was intended that worldwide implementation of this system would be completed by the year 2000. However, delays and reworks kept the GHS from becoming a worldwide reality quite that quickly.

Today, GHS has been widely adopted in the developed world with the U.S. being one of the last major economies to embrace the protocol. OSHA released a proposed rule incorporating the GHS into the HCS in late 2009. In March of 2012 the final rule was promulgated, with an effective date in May of 2012. At present, U.S. companies are enjoying a transition period that allows for dual use of both the new and the pre-existing systems. Figure 1 shows the effective dates.

Embracing classification

The previous version of the HCS law did not specify hazard classification as one of the required outcomes of the manufacturing process. However, the obvious requirement to transport a chemical beyond its point of manufacture did subject the product to the classification requirements specified for safe transport under the U.S. Dept. of Transportation (DOT) rules contained in U.S. 49 CFR Parts 100–185. The classification derived in the HCS rule should obviously be extremely similar to that derived from use of the rules in the U.S. DOT law. However, classifiers of chemicals under the U.S. DOT's regulations cannot rely solely on this classification. The HCS requires a substantially closer evaluation of the specific physical properties of a chemical in order to determine which of the physical hazards or health hazards, or both, that are prescribed under the HCS are applicable to that specific chemical. While this does introduce a somewhat more onerous evaluation process for the manufacturer, there is good news.

Prior to the issuance of the new rule, hazard evaluation was left in a somewhat murky status. The downside risk was the attendant liability involved. In the event of an accident or incident, it relied on, and thus left open to question, the specific expertise of the risk evaluator — thus exposing the manufacturer to the risk that such expertise (and the attendant responsibility to exercise due diligence) might be determined as inadequate.

The new rule solves this issue by setting forth very specific guidance, which must be followed to classify chemical hazards as well as to assign specific warnings and precautions to the hazard communication data assigned to them. Tabular data are used to determine actual ranges of performance (for example, flash points for flammable liquids, specific levels of inflicted damage for corrosives and so on) for the substances in question, which are then assigned that category and level of risk. Assuming correct evaluation of the physical data, this redirects potential liability away from the classifier and standardizes the risk set to be applicable to all manufacturers. The situation where one manufacturer's HCS warnings differ from another's for the same substance at the same amount, physical form, and level of concentration should be ameliorated.

Classification tables and other required data are found in the appendices to the rule (the full final rule can be read in Ref. 1). Appendix A references health hazards, such as substances that are very generally harmful in some fashion to human beings through their effect on the body. An example would be acute toxicity — the substance produces immediate illness or injury.

Appendix B references physical hazards, such as substances that have physical properties that may cause harm to a human being if activated in their proximity. An example would be flammability — the substance can ignite and the resultant fire is potentially harmful. Hazard classifications are listed in Figure 2.

These appendices relate specifically to the corresponding text in the rule itself. They are designed to lead the user through a logical sequence by comparing the physical properties of the substance to be classified with the data presented, and simply "plugging in" the values displayed into the tabular data presented. Unless the substance is of an extraordinary nature, this will lead to a correct classification. This classification will then be used to identify the required hazard warning information that is to be presented on both labeling and in safety data sheets (SDSs) — the SDS format replaces the familiar MSDS format under the new rule.

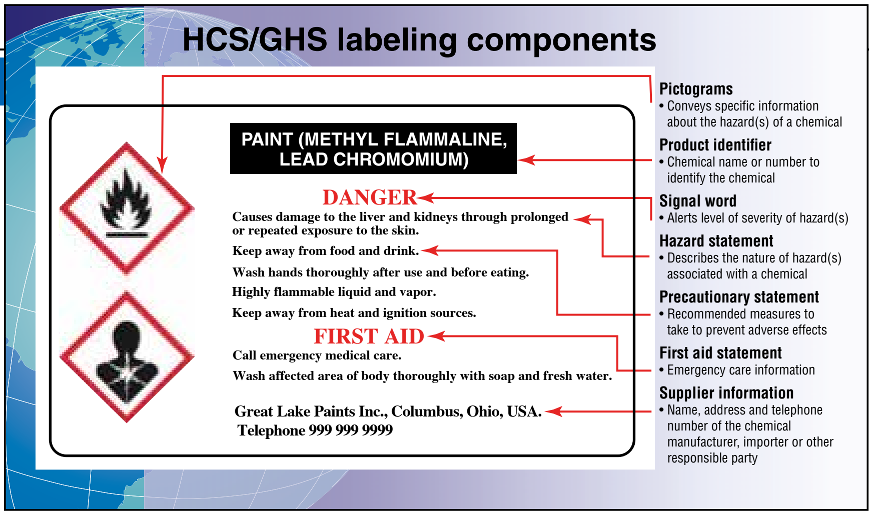

FIGURE 3. This sample label displays the legally required elements for a fictitious sample chemical

Deriving a classification then triggers a set of required responses and information presentations that must be included on the SDS, and on the applied hazard warning label for the container. Again, note that this label is not the same as that to be applied in the case where the container also serves as the primary shipping vessel for the product, rather than only as an "end-use" container. The requirements set forth in U.S. DOT rules are not satisfied through the application of HCS warning labels.

Conversely, transport labels do not fill the legal requirements for hazard warning under the HCS rules. The two, though seemingly related, are mutually exclusive of each other. In the case where the container serves both purposes, then both warning systems must be applied. The law, as written, was unclear on this point. However, since its inception, OSHA has clarified this point, allowing for simultaneous usage when required. A sample label displaying the legally required elements for a fictitious sample chemical is displayed in Figure 3.

Looking forward

At the time of writing this article, the new rule remains in its transition period. Classification may presently be performed or not. However, the expectation from industry is that manufacturers will provide the required data sooner rather than later. As mentioned above, this transitory window will close in June 2015, when all new containers shipped will be required to be compliant with the new standard.

While the new HCS rule using GHS-based classification elements is more technically challenging than the previous iteration of the HCS, it offers standardized procedures for classification and the assignment of risk that will make the job of compliance for manufacturers less a matter of individual company-based expertise and more a matter of simply following the same broad and legally defined path as the entire industry. It will limit risk to classifiers by removing the uncertainty that was attendant to the previous rule. Once fully implemented, it will lead to easy, logical classification of new products and an attendant easing of the path to market. ■

Edited by Dorothy Lozowski

References

1. U.S. 29 CFR 1910.1200; www.ecfr.gov/cgi-bin/text-idx?c=ecfr&rgn=div8&view=text&node=29:6.1.1.1.1.1.1.36&idno=29

Author

Paul Burgess is a dangerous goods safety advisor (DGSA) and a staff regulatory specialist at Labelmaster (5724 N. Pulaski Rd., Chicago, IL 60646; Phone: 773-478-0900; Email: pburgess@labelmaster.com; Website: www.labelmaster.com), a provider of regulatory compliance products, software and consultation services. Burgess' training and experience include degrees from both the University of Washington and Governor's State University, as well as professional certification as a U.S. Environmental Protection Agency (EPA) Hazardous Waste Operations and Emergency Response Standard (HazPower) specialist. He is also certified in the Federal Transportation Worker Identification Credential (TWIC) program. Burgess has more than 30 years of experience in environmental health and safety, hazard communications and dangerous goods. His experience includes work in the military, interstate trucking, heavy manufacturing and common carrier railroad settings.

Feature Report

Plant Revamps and Turnarounds: Some Lessons Learned

FIGURE 1. After an internal fire, the column had to be supported to prevent it from falling onto a pipe-rack

Petr Lenfeld
GTC Technology Europe

Ian Buttridge
GTC Technology US

Although time is always precious, taking shortcuts and skipping standard procedures can be costly

A plant turnaround is always challenging in the chemical process industries (CPI). But with proper planning and reliable procedures in place, last-minute time crunches and failures can be prevented. When haste combines with faulty methods, costly problems result.

This article presents three examples of actual plant turnarounds and the lessons that can be learned from them.

CASE STUDY NO. 1: SOUR-WATER STRIPPER

A sour water stripper (SWS) is a relatively small unit that treats wastewater from other process units of the plant, in this case a petroleum refinery. After treatment, the wastewater is directed to the sewage system, wastewater plant and ultimately to a nearby river.

The plant

This particular plant has no spare SWS unit, so in case of failure, the entire refinery must be shut down because untreated water is prohibited from being discharged into the river.

A sour-water storage tank may be used in an emergency with a capacity for five days of normal wastewater accumulation. In the event that the SWS is down, it must be repaired and started within the five days, otherwise the entire refinery must be shut down as mentioned before.

In this instance, the SWS column was packed with metal random packing. Column performance was steeply decreasing, because of packing fouling. The column had to be cleaned immediately, before the contaminants concentration in the treated water reached an unacceptable limit. A five-day turnaround was planned, which was long enough to shut-down the SWS, unload the metal rings, clean the rings and repack the column, and finally to restart the SWS unit. All refinery units were running at minimum capacity, directing all sour water to the five-day storage tank. Under normal circumstances, this should be a routine cleaning operation.

Fire

It is well known that pyrophoric iron is formed or accumulated in SWS units [*1*]. When the unit is put out of operation, the standard safety precaution is continuous washing with water to keep all internals wet and prevent pyrophoric iron from self-ignition and subsequent column fire. In this particular unit, operators had never run across pyrophoric iron before. Therefore (and due to the winter conditions), this "wet procedure" was not applied. The SWS column was not continuously washed with water, but opened after steam-out under dry conditions. This short-cut caused a dangerous situation with serious plant operational consequences.

As one might expect, when air entered the hot column, pyrophoric iron self-ignited, resulting in a column fire. Although the manholes were closed immediately and nitrogen was fed into the column, the fire inside continued. Temperatures inside the column reached 2,000°F; the column shell became warped and bent, and the tower internals were found melted into stainless-steel "icicles." The fire was extinguished at the last moment before total shell failure. Fortunately, the column did not fall onto the nearby pipe-rack, but it had to be secured with a mobile crane to prevent its fall (Figure 1).

Problem

Having no spare SWS unit, the five-day sour-water-storage tank slowly filled with water. Only five days were left to fix the problem or find another solution, after which the refinery would have to be shut down. Plant shutdown in winter time was a nightmare for plant management due to the extreme time and cost involved.

The fire occurred at 8:00 a.m. By 10:00 a.m., it became clear that the column could not be used anymore and had to be replaced or at least shop-repaired. But there was no chance to make repairs within the five days — repairing the shell in the shop and acquiring replacements for the damaged internals were estimated to require a minimum of two weeks. General frustration ensued and an emergency team was set up for express column-shell repair. By noon, it became clear to the troubleshooters that another column was needed to process sour water.

Feature Report

TABLE 1. LPG DEBUTANIZER PERFORMANCE BEFORE AND AFTER TURNAROUND

	Before turnaround	After turnaround
C4 purity	0.5 wt.% C5	20 wt.% C5
C5 purity	1 wt.% C4	20 wt.% C4
Reflux	valve 60% open	valve 60% open
Steam to reboiler	valve 50% open	valve 5% open

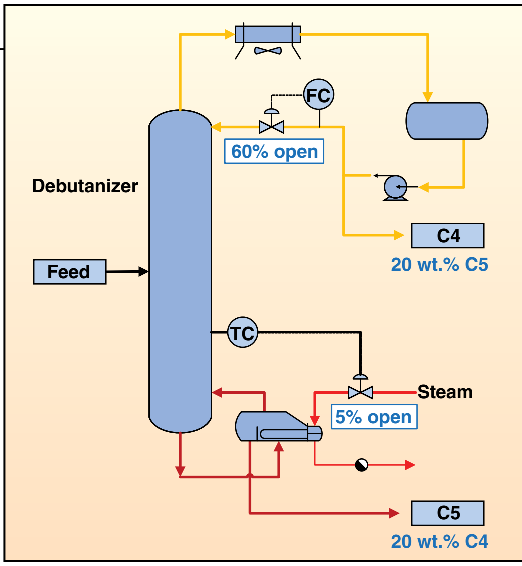

FIGURE 2. This flowsheet shows the LPG debutanizer in Case Study 2 after turnaround, and its performance (see also Table 1)

How to make a spare SWS

A sour-water stripper looks like a simple, "easy to find a replacement" distillation column. However, this is not true. Although the SWS is not a big complex column, it is very specific in metallurgy and auxiliary equipment. A suitable spare column must have a sufficient capacity, appropriate design pressure and the correct material of construction (as well as its reboiler, condenser, reflux drum and reflux pump). Perhaps more important is the offgas route from the SWS.

In this case, the offgas from the SWS is routed to a sulfur recovery unit (SRU), so the spare SWS must be connected to the SRU as well. Considering all the factors, the SWS is quite a unique unit. There was only one potential candidate for a spare SWS meeting all requirements — the amine unit regenerator.

Coincidentally, there was one idle amine regenerator at a nearby hydrotreater unit that was recently set on hot circulation to reduce sour water production.

Two teams had been working in parallel — one team for the SWS column repair and internals supply, and another team for the spare SWS design. The author was a member of both teams. The following steps were subsequently taken:

1. At 2:00 p.m. the amine unit regenerator was checked for sufficient capacity.
2. By the end of the day, the temporary cross-connection piping was specified.
3. Within the next two days, the temporary lines were designed, assembled, and pressure tested.
4. The amine-regenerator control screens in the distributed control system (DCS) were reprogrammed for new operating conditions.

A happy ending

The spare SWS was successfully started ten hours before the sour water tanks filled up. A plant shut-down was avoided.

There was enough time to make a thorough shop-repair of the damaged SWS column. The warped SWS column was cut into three pieces. The damaged part was replaced with a new cylindrical section. New internals were designed, manufactured and delivered on an emergency schedule within eight days. The SWS unit was successfully put back into operation after a two-week repair period.

Lessons learned

1. SWS units are prone to fouling and pyrophoric formation. Special precautions shall be applied for SWS cleaning.
2. Trays should be preferred to packing for SWS service, because trays are easier to clean and less prone to metal fire.
3. The standard five-days capacity of a sour-water storage tank might not be sufficient in the case of serious trouble — a spare plan should be prepared to avoid costly plant shutdown.

CASE STUDY NO.2: LPG DEBUTANIZER

A petroleum refinery was completely shut down for planned maintenance and cleaning. However, the turnaround was not well managed, causing the employees to rush their work and not follow some procedures properly. As a result, after startup, a liquefied petroleum gas (LPG) debutanizer (Figure 2) did not meet the same product quality that was regularly met before the turnaround. Both top and bottom products were off specification and the column did not provide any fractionation despite operators maintaining the same reflux rate as before the turnaround.

Problem analysis

Insufficient product separation had been first diagnosed as being caused by extremely low tray efficiency. It was suspected that the maintenance crew left open manways in the column trays. Later, a close look at operating conditions showed that the column was well refluxed, but the reboiler duty did not match. The reflux rate had been the same as before the turnaround, but the steam rate to the reboiler was close to nothing (Table 1).

The debutanizer column virtually violated an enthalpy balance. Instrument readings and control valve positions had been verified in the field, and it was concluded that both flowrate readings were correct. Distillation columns can't run without any reboiling, but this mysterious debutanizer did.

The explanation of the mysterious behavior was elementary — reflux liquid was not coming down through the column, but instead, it had been entrained back to the reflux receiver and re-circulated.

Finding the root cause

Heavy liquid entrainment is usually addressed as jet-flood, caused by ex-

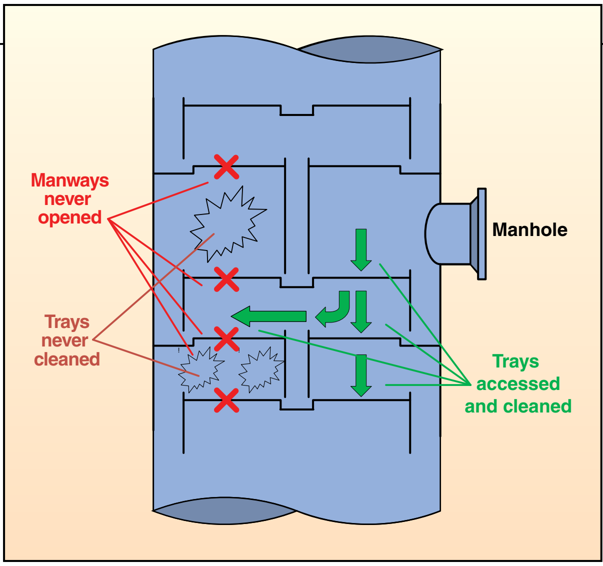

FIGURE 3. Improper cleaning of the LPG debutanizer caused a buildup of rust and dirt

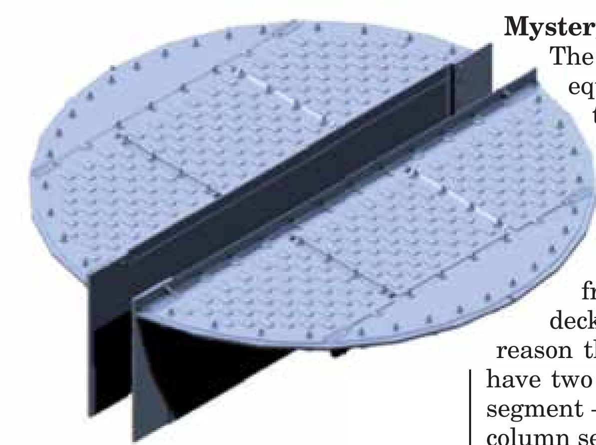

FIGURE 4. A modern design of a two-pass valve tray includes fast opening manways on both sides

treme vapor load. In this case, the vapor rate could not cause any entrainment because the reboiler duty was almost none. One suspicion was that one of the tray downcomers was blocked with a piece of mineral wool insulation or other debris.

Plant management was not very pleased with this explanation, commenting that "The column has been just cleaned and inspected as being in perfect operating condition, but you claim the major malfunction is caused by some debris? Should the LPG plant be shut down again for an inspection and cleaning that was just performed?" Management needed a justification due to the expense involved with another shutdown. The troubleshooter proved that the problem was real and it could not be fixed without a unit shutdown.

The short-term shutdown of the LPG unit was carried out, keeping the rest of the refinery running at a low capacity and temporarily flaring LPG as there was no spare LPG plant. The debutanizer column was open, after water washing and air purging. The inspector's first reaction was surprise. Everything seemed fine and the column seemed clean.

Mystery solved

The debutanizer column was equipped with two-pass trays, with side and central downcomers. On every other tray, the central downcomer forms a wall in the column center, effectively blocking access from one side of the tray deck to the other. It is for this reason that two-pass trays should have two manways — one for each segment — to ensure access to both column sections.

In the case of this particular LPG debutanizer, the trays were of an old design, with separate I-beam support and bolted decks. The maintenance crew "did not waste time with opening both manways because trays had been always clean in the past." Only one manway had been opened in every tray for inspection and cleaning. On trays with central downcomers, only one half of each tray had been cleaned as a consequence. This incorrect cleaning procedure has been applied for 20 years, since the column first started up. The sections "behind downcomer" had never been inspected or cleaned. When both manways were opened, every other tray was found to be covered with a 1-in. layer of rust and dirt. Valves were stuck and some downcomers were blocked. In the past, cleaning was performed by flushing with water, so washed out dirt settled in the non-accessed tray sections until they became completely blocked (Figure 3).

Lessons learned

1. Cleaning and inspection procedures shall not be compromised, despite turnaround time constraints.
2. "Sweeping dirt under the rug" is not the proper cleaning procedure.
3. If the trays were of modern design, with fast opening manways and locks (Figure 4), the maintenance crew would not have compromised the inspection and the cleaning procedure.

CASE STUDY NO. 3: WRONG LEVEL INDICATION

A solvent-recovery column at a petrochemical plant (Figure 5) was revamped, converting the existing one-pass trays to two-pass, high-performance trays to account for a large capacity increase and much higher liquid flowrates. After startup of the unit, an unstable reflux-drum level was observed making control of the column difficult.

The diagnosis by plant personnel was that the unstable reflux-drum level was due to flooding of the tower and entrainment carryover. The immediate solution proposed by plant personnel was to revamp the tower to change from trays to packing.

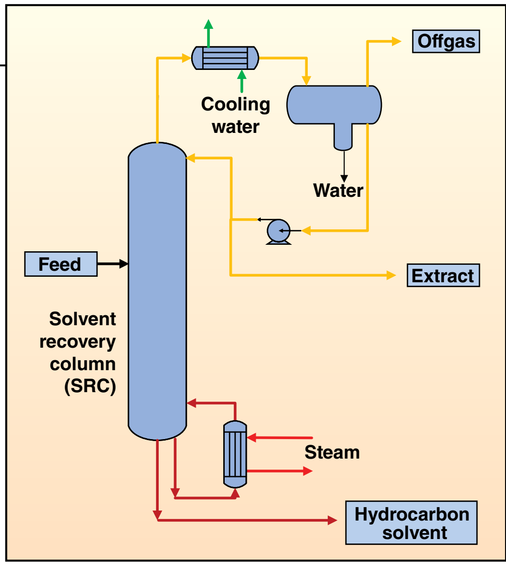

FIGURE 5. The tower configuration for Case Study 3 is presented here

Trays versus packing

The immediate reasoning for selecting packing was that a packing could be chosen that would appear to have more capacity than the high-capacity trays currently in the tower, and that the nominal HETP (height equivalent per theoretical plate) reported by vendors would be more than enough to achieve the number of theoretical stages required. The calculated flood fraction of high-performance trays is 79%, whereas the calculated flood fraction of 125 m^2/m^3 X-type structured packing is 70%.

The nominal packing HETP for this type of packing was reported as 1.2 m. This appeared to meet the separation requirements, as modeling had shown the revamped trays were generating five theoretical plates at 610-mm tray spacing. The height available in the tower appeared more than enough to achieve the separation with the benefit of a lowered flood value.

It was at this point that fractionation specialists were called in and the dangers of applying a nominal HETP to different applications were noted. In this case of solvent separation, where polar components are involved, extrapolating HETPs used for low relative volatility non-polar hydrocarbons should not be considered. By cross-consulting an operating data bank, it can be seen that for moderate pressure applications, a structured packing surface area of 200–250 m^2/m^3 would be required to achieve the same or better efficiency than the trays, regardless of reported nominal values.

At the specific liquid flux evaluated at these conditions, the capacity of even a high-capacity structured packing at this specific surface area would be much less than the high-performance trays currently installed in the tower. Finally, the revamp scope and downtime required to complete a revamp from the tray-to-packing solution would be costly.

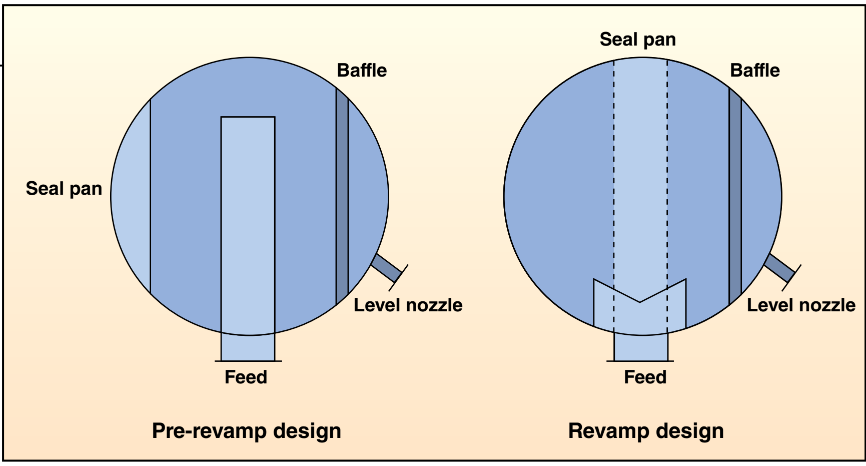

FIGURE 6. Pre-revamp (left) and post revamp (right) configurations are shown here

Root cause evaluation

Examining the design of the trays themselves resulted in no immediate cause for concern, and indeed rating methods resulted in a predicted flood value of 79%. Entrainment and flooding were not expected at these conditions.

An examination of the raw data and the actual symptoms would need to be conducted. The main operating issues came about as extremely unstable overhead level and the inability to control the overhead pressure. As the overhead pressure increased, the operators reacted by reducing steam to the tower bottoms or decreasing reflux to the tower. The overhead reflux-drum level would dramatically rise to high levels and the control system began "hunting" for the proper level. If overhead pressure decreased below the set point, the reflux was increased or steam was increased. Overall it was difficult to reach a steady-state operating point.

The unstable operation was assumed to be caused by flooding in the tower. When evaluating the tower for other flooding signs (such as higher pressure drop), it was found that no flooding symptoms where observed. The bigger problem was to diagnose what the root cause was, and to find the symptom of the root cause. This would only be found after examining the tower under more stable conditions.

Reduced feed charge operation

At a feed charge-rate of 50% of the revamp conditions, a clearer picture was observed. At these conditions, it was noticed that the bottom level instability preceded the overhead reflux instability. In this case, the bottom level would rise resulting in increased steam or decreased reflux, which would cause instability in the overhead level. The bottom level would dramatically fall as it reacted to the step changes. At these conditions, the overhead pressure was relatively stable.

Field observation

Incorrect field measurements — level measurements in particular — are not uncommon issues faced by troubleshooters. The best way to confirm that these issues are real is to actually walk to the unit and look (visual check). In this case, the problem became immediately obvious when liquid was observed to be draining into the top level nozzle at the bottom of the column.

Tower internals/control nozzles

In general, designers of tower internals should evaluate the new internals of a tower for the arrangement relative to the process control nozzles. In the case of simple revamps where the number of passes remain the same, this is relatively trivial. In the case where the tower is being converted from trays to packing, or in the case where the number of passes changes, some extra care should be considered. In this particular case, the internal-equipment designer was provided with information to evaluate all process and control nozzles that were located inside the new trays; however, no information was shown for the bottom level nozzles relative to the reboiler return. Figure 6 compares the prior revamp bottoms arrangement to the new arrangement.

The revised arrangement directed the two-phase reboiler return directly into the top level nozzle (Figure 7), which resulted in liquid draining into the level. However, this arrangement resulted in control issues. A seemingly high level in the product draw saw operation increase the reboiler steam, which in turn would follow with a rise in reflux flow.

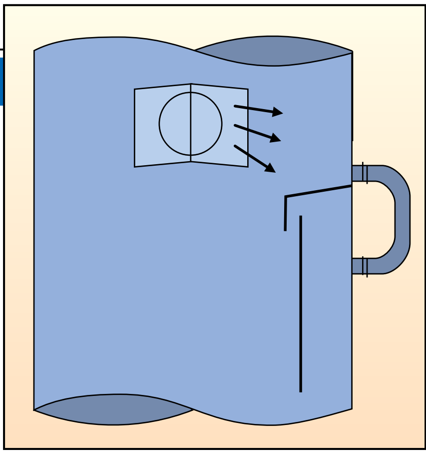

FIGURE 7. Only after visual inspection was it found that liquid entrained into the top level nozzle

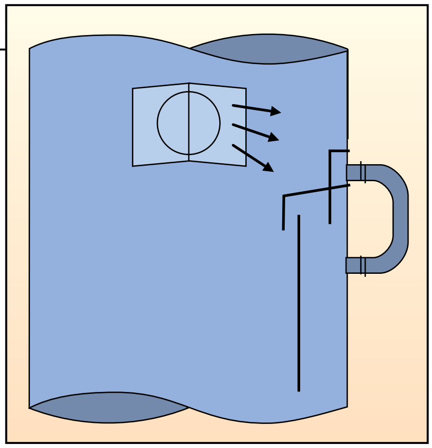

FIGURE 8. The liquid entrainment problem was solved with a simple field modification of the level nozzle

Modifications

Adding new level taps at an elevation below the top of the reboiler baffle arrangement was probably the most straightforward option. However, adding new nozzles may require PWHT (post weld heat treatment) or at least additional approval and time. In order to further minimize the downtime, a simple solution was used: installing a half pipe to seal off the top level nozzle from the reboiler return. This half pipe was simply extended through the baffle, as shown in Figure 8. The result was much more stable tower operation at the full range of feed rates.

Lessons learned

1. An evaluation of tower-internals selection with regard to process nozzles should be considered not only for mechanical interference, but also in regards to a detailed analysis of fluid flow and process control. An extra review step with all parties involved can further eliminate future issues.
2. Careful troubleshooting and diagnosis by specialists in the particular engineering discipline is a key to correct diagnosis and preventing further costly revamps that do not address the root cause. ■

Edited by Gerald Ondrey

References

1.. Mary Kay O'Connor Process Safety Center, "Best Practices in Prevention and Suppression of Metal Packing Fires," Texas 2003.

Endnote

The contents of this article was first presented at the 2013 Spring Meeting and 9th Global Congress on Process Safety of the American Institute of Chemical Engineers (San Antonio, Tex.; April 28 – May 2, 2013).

Authors

Petr Lenfeld is senior process engineer at GTC Technology Europe s.r.o. (Prikop 6, 60200 Brno, Czech Republic; Phone: +420-511-118-005; Fax: +420-545-174-601; Email: plenfeld@gtctech.com), and specializes in process design and troubleshooting. He holds a Ph.D. degree in chemical engineering from the Institute of Chemical Technology, Prague, Czech Republic.

Ian Buttridge is the technical director for GTC Technology Inc. (1400 WestPark Way, Building 100, Euless, TX 76040; Phone: +1-817-685-9125; Fax: +1-817-685-0236; Email: ibuttridge@gtctech.com) and specializes in fractionation applications and equipment design. He holds a B.S.Ch.E. from Texas A&M University.

Calculations in Process Engineering

Knowing how specific calculations differ can focus your efforts

Mohammad Toghraei
Engrowth Training

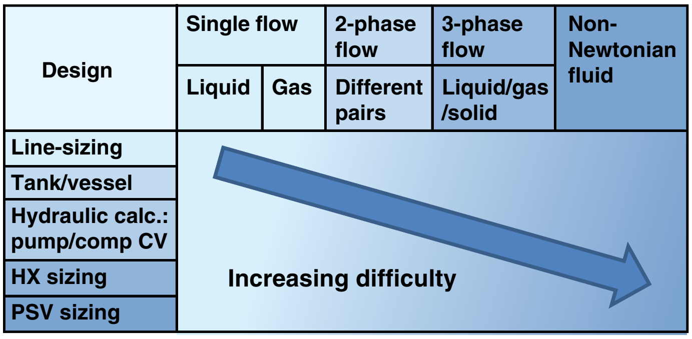

FIGURE 1. The most popular types of calculations are related to the sizing of lines, tanks, vessels, pumps, compressors heat exchangers and PSVs. This figure shows these general items and their variations

The topic of carrying out process engineering calculations in the most effective manner can be considered in these four ways:
1. The purpose of the calculation
2. The content of the calculation
3. The method used to carry out the calculation
4. The performer of the calculation

The purpose of the calculation

Engineers typically carry out calculations for a variety of purposes including the following:

a) To conduct a technical or economical evaluation of a plant or specific unit (such as a heat and material balance), to carry out evaluations in the early stages of the project, or for use while writing studies or technical memos for stakeholders

b) To size, rate or specify a piece of equipment

c) To generate a specific operational procedure

Sizing, rating, and specifying are three distinctly different goals of calculation efforts. Process sizing means defining all the (process) aspects of the equipment, so that the manufacturer can produce it with little process knowledge. Sizing efforts typically involve calculations that aim to identify all the unknowns associated with one equipment component, to enable the fabricator to produce that component.

By contrast, when specifying an equipment component or instrument system, the engineer must define a specific amount of information for the manufacturer, and can then expect the manufacturer to satisfy those requirements. For example, when an engineer plans to buy a pressure safety valve (PSV), he or she specifies the required setpoint of the PSV, the release rate and a few other items. This effort does not require the engineer to design a PSV by sizing the orifice diameter, spring constant and so on.

It is clear that no process engineer designs a centrifugal pump just by calculating the impeller diameter and vane angles. Today, process engineers can expect that the manufacturer will provide much detailed information to support the process of designing and specifying process equipment. As a result, there is very little "pure designing" in today's specialized market; rather, there is always an element of specifying involved when carrying out sizing calculations.

While specifying and sizing are concepts related to equipment or instruments that are planned to be procured later, rating is an activity that involves calculations associated with existing equipment components. During rating, the question that the engineer is trying to answer is whether an existing component can be used in a specific new application or not. Rating efforts require evaluating current equipment for a specific type of service and conditions.

The content of the calculation

Calculations involve the following three steps:

- Step 1 requires identifying suitable input values (assumptions)
- Step 2 involves choosing and using an appropriate methodology — one that uses the parameters established in Step 1 — to arrive at an answer that has the required accuracy in the available time slot
- Step 3 involves the evaluation and verification of assumptions and results

Step 1. Identifying suitable input values (assumptions). Junior engineers tend to struggle with this step. Too often in the university setting, the instructor provides the "given values," whereas in real-world situations, it is up to the engineer to determine which input values and assumptions are relevant. This effort requires three sub-steps:

1. Find effective parameters. Engineers need to find the parameters that will impact the results they are seeking. For example, within a specific issue, there could be three parameters M, N and P. In this step, these three parameters need to be evaluated in order to recognize the ones that are most relevant to the problem at hand. At this stage, the engineer should be able to evaluate the three parameters of M, N, and P to determine that, for example, M and P are the only required parameters (or the most relevant parameters) and these will be considered further in Step 2. Or with the level of required accuracy, perhaps only *M* will be considered in Step 2.

2. Select a numerical design value. In this step, a numerical value needs to be assigned or determined for the selected parameter(s) identified in the previous step. The magnitude of the design or rated parameter is that number (or range) that covers all the different scenarios that could be encountered during the operation of the plant, plus a reasonable margin. For example, M_{design}= 6 could be a wise decision when parameter *M* can accept magnitudes of 2.0, 3.5 and 5 during plant operation.

Trial-and-error efforts, which typically require an educated guess at the beginning and some adjustments made along the way based on final results, are often required. Certain rules-of-thumb can help engineers to make a better preliminary guess, and this can help to decrease the calculation time. The reason for this iterative route is that each methodology has some limitations, and at the end of the first run of calculations, any limitations should be checked to make sure they have been met.

Step 2. Choosing the right methodology. This step is very important. The selected methodology must be accurate and at the same time, the required engineering time for that method should be justifiable. A skilled process engineer should be able to identify calculation methodologies for each situation that meet the specific accuracy and time requirements or constraints.

For example, during pipe sizing, an engineer should be aware of the standard pipe sizes that are already available on the market. Designing a given pipe that is sized to, for instance, two decimal points, does not make sense, as the market already provides defined pipe sizes.

Meanwhile, in some cases, one scenario can be "converted" to another case, to enable the use of a simpler version of the methodology and shorten the calculation time. Such a "conversion" effort is only acceptable if this new scenario is the more conservative approach. However, in some cases, the more simplistic and conservative approach may be too conservative in a way that makes it unacceptable. In such cases, the original — albeit more complicated — route must be taken. This may occur in situations in which the worst-case scenario has led to extraordinarily oversized equipment or equipment that is overly difficult or costly to construct.

Discussed below are some of the popular simplifying conversions that are widely used today:

1. The thermodynamic approach versus the kinetic approach. Most often, the thermodynamic approach is selected due to its well-established methods and its popularity in terms of published works and data. For example, finding the evaporation rate from a surface of a liquid is challenging. It depends on different parameters and requires the consideration of various phenomena including heat transfer and mass transfer. However, by changing the approach from kinetic (in which the evaporation rate is calculated) to thermodynamic (in which only the saturated pressure of the vapor above the liquid surface is calculated), the effort will be simplified.

2. Assuming steady-state vs. unsteady-state conditions. Most often, the steady state is selected, thanks to its well-established methods and simplicity of its calculation using inexpensive software or even a spreadsheet progra. For example, analyzing PSV opening phenomena is not an easy task as it is inherently an unsteady-state operation-However, during PSV sizing, we often pick the largest flowrate that is considered a steady-state case for a mere few milliseconds during the opening of the PSV.

Step 3. Verifying assumptions and results. This is not merely the end of the task, but is a very crucial step, the results of which may call for a second run-through or reconsideration of Steps 1 and 2.

As mentioned, the design process might need some iteration to reach the most appropriate results. For example, if the calculation is sizing or specifying, it will result in one of the following three conditions:

1. A case involving an extremely inexpensive or small piece of equipment. In this case, the equipment often cannot be custom-made but must be selected off-the-shelf. As a result, the final piece of equipment may not be exactly what is required via the calculations, and adjustments may be required to mate the piece into the overall configuration. For this reason, it may be efficient to have the specifications of standardized (off-the-shelf) equipment on hand throughout the course of the calculations, so that adjustments can be made as the calculations are being constructed.

2. A case involving moderately sized or moderately complex equipment. In this case, the equipment will typically be custom made in the shop. It is important to keep in mind the dimension limits of the shop in question. If the item is too large, it will have to be fabricated in the field, and the price will be considerably higher. In an illustrative case, a careless designer may design a tank with diameter half a meter above the limits of the shop, and therefore unnecessarily cause a price jump because the tank suddenly changes from a shop-fabricated item to a field-fabricated one. Shop limitations are imposed not just by the machinery-manufacturing limits in the shop, but by the road restrictions or overpass weight limits that will affect the transportation of the equipment to its final destination.

3. A case involving a large piece of equipment. In this case, the equipment will typically be custom

CHOOSING THE BEST MEDIA

Some companies accept calculations that are done by hand, while others will utilize or even require the use of specific software. With hand-done calculations (as opposed to those carried out using a spreadsheet program), a clear disadvantage is that any adjustments will require all of the subsequent steps to be re-done (That is, there is no way to link equations so that they will be automatically updated if a given parameter is changed).

By comparison, spreadsheet programs, such as Microsoft Excel or an equivalent data processor, are designed so that any changes will result in the computer adjusting all subsequent steps automatically. The disadvantage to this is that the calculation process is not always visible, as some formulas may be buried within a cell. To maximize the advantages and minimize the disadvantages of a spreadsheet program, the following steps should be taken:

1. Ensure that all of the calculations are interconnected in such a way that altering the inputs will alter the results accordingly. Take care in this effort, as any disconnections may be disastrous, because adjustments to the input will not result in appropriate alteration to the output.
2. Ensure that all manual input is visible and clearly marked to give the designer the flexibility to alter it. Any hidden manual input may not be recognized by a new designer as a potentially adjustable value.
3. Ensure that new users do not disable any pre-existing macros in the program.
4. Ensure that iteration calculations are enabled where required.
5. Ensure that the calculations are legible both on the computer and in print.
6. Ensure that when the flexibility of adding a new row or column is provided in a template, all of the information is transferable. Such flexibility exists in some modular pump-sizing spreadsheets. ❑

made in the field at a higher cost. This high cost is due to the fact that skilled workers and various required utilities will need to be shipped and present at the field in order to construct the larger components. As a result, this case is often used as a last resort.

The performer of the calculation

Generally speaking, each group of process engineers is expected to be able to carry out specific types of calculations, based on this rough classification:

Junior/intermediate design process engineers: Sizing of tanks and vessels; hydraulic calculations for pumps, compressors and control valves; sizing of heat exchangers; and PSV sizing after receiving release rates from an intermediate or senior engineer

Intermediate/senior design process engineers: All of the above items, in multi-phase cases (that is, two-phase flow for pipe sizing); separators (two- and three-phase separators, gas-knockout drums, sedimentation vessels, clarifiers); other industry-specific items (such as distillation towers for petroleum refining, and ion-exchange systems for water treatment); PSV sizing (performing the first steps of PSV sizing including defining pressurizing scenarios, finding the credible and governing scenario(s) and release rate calculation)

Senior design process engineers: Reactors, especially complicated ones, and industry-specific equipment. ■

Edited by Suzanne Shelley

Author

Mohammad Toghraei, P.Eng., is currently a consultant and instructor with Engrowth Training (www.engedu.ca; Phone: 403-808-8264; Email: moe.toghrae@engedu.ca). Toghraei has over 20 years experience in the field of industrial water treatment. His main expertise is in the treatment of wastewater from oil and petrochemical complexes. For the past seven years he has taken on different technical and leadership roles in water treatment areas of SAGD projects. Toghraei has received a B.Sc. in chemical engineering from Isfahan University of Technology and an M.Sc. in environmental engineering from the University of Tehran, and is a member of APEGA.

Optimization of a Steam Network

Proper configuration of steam-turbine drivers affects power generation in petroleum refineries

C.C.S. Reddy and S.V. Naidu
Andhra University

G.P. Rangaiah
National University of Singapore

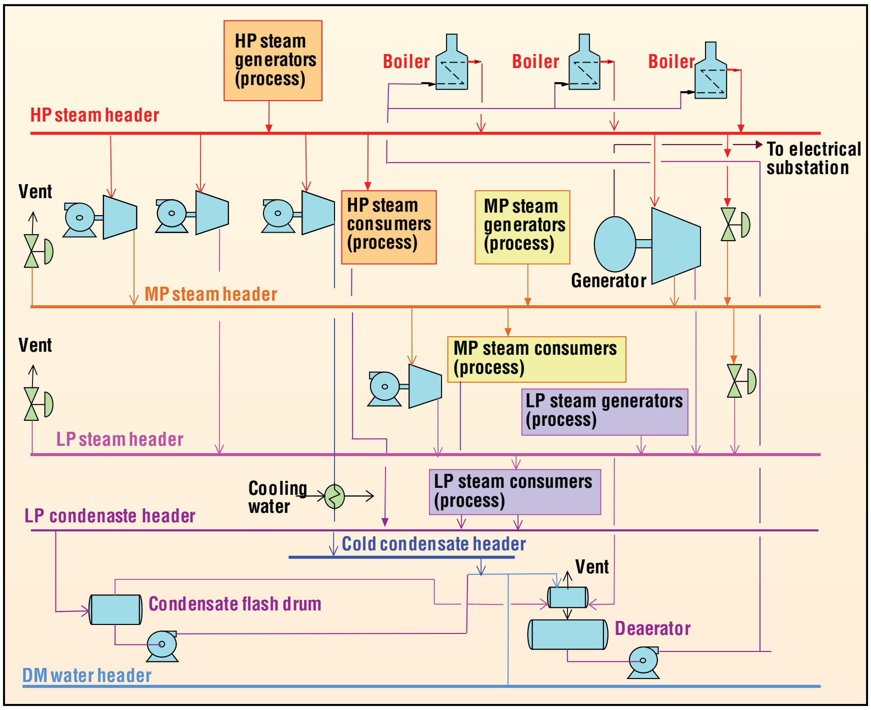

FIGURE 1. A typical petroleum refinery steam network features equipment such as turbines, generators, boilers and supply headers

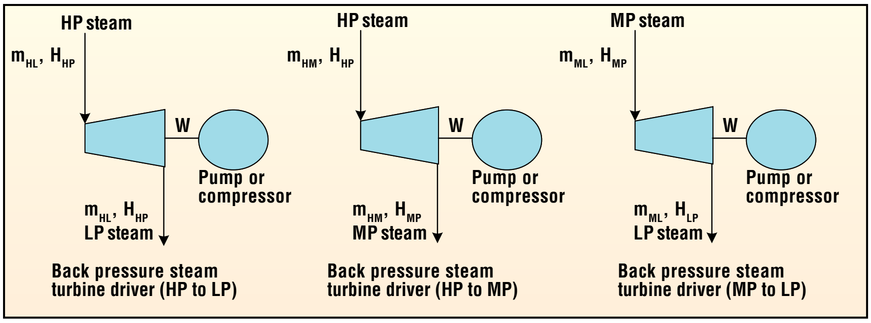

FIGURE 2. There are three different types of back-pressure steam-turbine drivers, based on their configuration relative to steam supply headers

Petroleum refineries generate power from a number of sources, including cogeneration plants and steam networks. Generally, steam networks use turbines to improve operational reliability, specifically as drivers for rotating equipment. Due to increasing energy costs, it is essential to maximize the power-generation capabilities of steam networks. This article presents a spreadsheet-based optimization model for a steam network. Figure 1 shows a typical steam network in a petroleum refinery.

For maximizing the total power generation, a mixed-integer linear programming (MILP) model is formulated by linearization of equipment models and use of a spreadsheet for estimating steam properties. The solution of this model determines the optimum operational configuration of steam-turbine drivers for maximum power generation, while satisfying constraints related to material balances, equipment selection and capacity limitations. One case study is presented to demonstrate the potential and benefits of the spreadsheet-based approach for optimizing steam networks.

Due to the large volume of steam required for power generation, and the various turbine equipment types, steam-system considerations have been the subject of many studies over the years [*6,7,10*]. However, almost all of these studies focused on steam systems with a few very large steam turbines, with greater than 1.2 megawatt (MW) output, for which models are developed by data regression. Significant errors will result if these models are applied to smaller steam-turbine drivers (below 1.2 MW output). Also, previous studies did not consider the effects of condensate recovery on steam-system optimization. An optimization model must also accurately represent very small steam-turbine drivers, since, for reliability purposes, petroleum refineries may drive pumps or compressors with smaller turbines, some of which may generate power as low as 5 kW.

This article's spreadsheet-based approach provides the flexibility to realistically evaluate a steam network, without the constraints and licensing fees incurred by using commercial process-simulation software. With accurate models for both smaller and larger steam tur-

NOMENCLATURE

a, a_0	Regression parameters in steam turbine model, kW
b, b_0	Regression parameters in steam turbine model (unitless)
a_1	Regression parameter in steam turbine model, kW/°C
b_1	Regression parameter in the steam turbine model, °C^{-1}
ΔH_{blr}	Enthalpy difference between generated steam and boiler feed water, kJ/kg
H_{BFW}	Specific enthalpy of boiler feed-water, kJ/kg
ΔH_{blr}	Specific enthalpy of condensate, kJ/kg
H_{CRLP}	Specific enthalpy of LP condensate, kJ/kg
H_{DW}	Specific enthalpy of demineralized water, kJ/kg
H_{FS}	Specific enthalpy of flash steam, kJ/kg, at deaerator's operating pressure
H_{HP}	Specific enthalpy of HP steam, kJ/kg
H_{MP}	Specific enthalpy of MP steam, kJ/kg
H_{LP}	Specific enthalpy of LP steam, kJ/kg
H_{SD}	Specific enthalpy of LP steam, kJ/kg, at deaerator's operating pressure
H_{in}	Specific enthalpy of steam at steam-turbine inlet, kJ/kg
H_{out}	Specific enthalpy of steam at steam-turbine outlet, kJ/kg
H_{is}	Enthalpy of steam at steam-turbine outlet pressure and having same entropy as inlet steam, kJ/kg
H_{vent}	Specific enthalpy of vent steam/gas, kJ/kg, at deaerator's operating pressure
ΔH_{is}	Isentropic enthalpy change across steam turbine, kJ/kg
ΔH_{real}	Enthalpy difference between inlet and outlet of the steam turbine, kJ/kg
i	Index for HP-to-LP back-pressure steam turbine
j	Index for HP-to-MP back-pressure steam turbine
k	Index for HP-to-vacuum condensing steam turbine
l	Index for MP-to-LP back-pressure steam turbine
L	Intercept ratio for steam turbine, W_{INT}/W_{max}
m	Mass flowrate of steam through the turbine, kg/s
m_{BFW}	Mass flowrate of boiler feed water, kg/s
m_{blr}	Mass flowrate of steam generated in the boiler, kg/s
m_{CR}	Mass flowrate of steam condensate, kg/s
m_{CRLP}	Mass flowrate of LP steam condensate, kg/s
m_{DW}	Mass flowrate of demineralized water, kg/s
m_{FS}	Mass flowrate of flash steam generated in the condensate recovery drum, kg/s
m_G	Mass flowrate of steam through steam-turbo generator, kg/h
m_{HPG}	Total mass flowrate of HP steam generated by the process, kg/s
m_{HPC}	Total mass flowrate of HP steam consumed by the process, kg/s
m_{SD}	Mass flowrate of LP steam for the deaerator, kg/s
m_{ld}	Maximum flowrate of steam through pressure letdown valve, kg/s
m_{LPG}	Total mass flowrate of LP steam generated by the process, kg/s
m_{LPC}	Total mass flowrate of LP steam consumed by the process, kg/s
m_{MPG}	Total mass flowrate of MP steam generated by the process, kg/s
m_{MPC}	Total mass flowrate of MP steam consumed by the process, kg/s
m_v	Maximum flowrate of steam through atmospheric vent valve, kg/s
n	Slope of Willian's Line, kJ/kg
p	Number of HP-to-LP back-pressure steam turbines
P	Total site power, including both shaft power and electrical power generation, kW
q	Number of HP-to-MP back-pressure steam turbines
Q_{fuel}	Heat required from fuel in the boiler, kW
Q_{steam}	Heat content of HP steam, kW
r	Number of HP-to-vacuum condensing steam turbines
s	Number of MP-to-LP back-pressure steam turbines
SR	Steam rate for the steam turbine, kg/kWh
ΔT_{sat}	Saturation temperature difference across steam turbine, °C
W	Shaft power produced by steam turbine, kW
WCS	Cooling water supply
WCR	Cooling water return
W_{INT}	Y-axis intercept of Willan's Line, kW
Y	Binary variable for steam-turbine optimization
α	Faction of deaeration steam vented through vent orifice
η_{boiler}	Boiler efficiency
η_{is}	Steam turbine isentropic efficiency
η_{mech}	Steam turbine mechanical efficiency
$\eta_{overall}$	Overall steam turbine efficiency

Superscripts

HL	HP-to-LP back-pressure steam turbine
HM	HP-to-MP back-pressure steam turbine
HC	HP-to-vacuum condensing steam turbine
ML	MP-to-LP back-pressure steam turbine
HML	HP-to-MP and LP extraction-type steam turbine
L	LP steam
M	MP steam
max	Maximum flowrate, kg/s
min	Minimum flowrate, kg/s

bines, the approach presented in this article also includes a built-in properties database for steam and water, which can be modified by users for studying energy-saving schemes and arriving at accurate steam costs. The model can also be linked with a plant's distributed control system (DCS) for realtime optimization.

Steam turbines

Steam turbines are used to convert part of the energy of steam into power, and there are many possible turbine configurations within a steam network [*12*]. Besides equipment such as turbines, boilers, generators and consumers, supply headers are also an integral part of any steam network. The steam network shown in Figure 1 includes a number of supply headers, including ones for low-pressure (LP), medium-pressure (MP) and high-pressure (HP) steam, as well as demineralized (DM) water. Turbines are installed between these steam-supply headers, in different configurations depending on power requirements, as well as refinery steam and electricity balances. Pressure-control valves are used to depressurize the steam and to vent any excess steam to the atmosphere. Steam turbines have two basic classes — back-pressure and condensing, which are shown in Figures 2 and 3, respectively. Furthermore, back-pressure steam turbines have three types of configurations based on their placement relative to the LP, MP and HP steam headers (Figure 2). See the "Nomenclature" section for definitions of symbols and abbreviations that will be used throughout the article.

Drivers and motors

The hallmark of steam-turbine drivers is reliability. Generally, steam-turbine drivers incur more operating costs when compared to motor drivers, mainly due to their smaller size and lower efficiency. However, steam turbine drivers are frequently used, because their reliability is desirable during power failures. For instance, in many facilities, critical process pumps are installed in pairs with a parallel arrangement where one pump is installed with

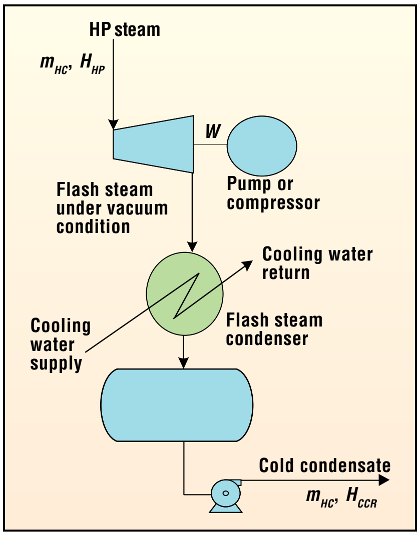

FIGURE 3. A condensing-type turbine involves cooling water and cold condensate return (CCR) flows, which are taken into account for optimization

an electric motor and the other with a steam-turbine driver.

An understanding of driver types is valuable, as selection of drivers can impact a refinery's pressure-relief requirements. Selecting the best driver type for a pump or compressor depends on whether the pump or compressor in question is critical to operations. If the equipment is deemed non-critical, then the power can be switched between a steam-turbine driver and an electrical driver, as needed. These steam-turbine drivers are called switchable turbines.

However, if a pump or compressor is critical for the process, a steam-turbine driver is always used. Such steam-turbine drivers are non-switchable turbines. Non-switchable turbines are inflexible for optimizing steam networks, since a fixed amount of steam is required to flow through the turbine continuously. Switchable turbines and steam-turbo generators (which generate electrical power) are much more flexible with regard to optimization, as steam flow can be adjusted based on demand or relative price of generated power [*10*].

Turbine performance

Efficiency of a steam turbine varies nonlinearly with the steam flowrate or power generation. However, the power-flow relationship of a steam turbine over the entire range of operation can be described by a linear relationship known as Willan's Line [*10*] given by Equation (1).

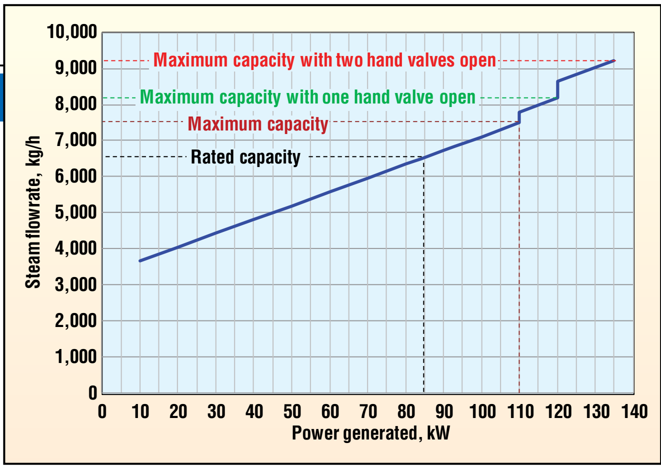

FIGURE 4. Willan's line allows for determination of the power-flow relationship for a turbine. In this example, the steam consumption and power generation in a small steam turbine are plotted. The steam's inlet pressure and temperature are 254°C and 11.5 bars, respectively, with an outlet pressure of 4.5 bar

$$W = n \cdot m - W_{INT} \quad \mathbf{(1)}$$

Steam-turbine vendors usually show steam consumption on the *y*-axis and power generated on the *x*-axis, as illustrated in Figure 4. Steam turbine performance can be accurately estimated from the performance curve, which is supplied by the turbine's manufacturer. If the performance curve for a multi-valve steam turbine is unavailable, then its performance can be predicted by models available in the literature [*10*]. One such model is described here. Slope (n) and y-intercept (W_{INT}) in Equation (1) for a steam turbine can be calculated from Equations (2) and (3).

$$n = \frac{L+1}{b}\left(\Delta H_{is} - \frac{a}{m_{\max}}\right) \quad \mathbf{(2)}$$

$$W_{INT} = \frac{L}{b}\left(\Delta H_{is} \cdot m_{\max} - a\right) \quad \mathbf{(3)}$$

The regression parameters a, b and L are related to the saturation temperature difference between the inlet and outlet conditions of the steam turbine, according to Equations (4) and (5).

$$a = a_0 + a_1 \cdot \Delta T_{sat} \quad \mathbf{(4)}$$

$$b = b_0 + b_1 \cdot \Delta T_{sat} \quad \mathbf{(5)}$$

Note that these parameters are obtained from published data and may not accurately predict the performance of all multi-stage steam turbines [*12*]. It is recommended to perform independent regression analysis for the particular steam turbine from the manufacturer's performance data or from actual operating data. Actual work produced in a steam turbine can be calculated using Equations (6) and (7).

$$W = \eta_{is}\eta_{mech}\Delta H_{is} m \quad \mathbf{(6)}$$

$$\eta_{is} = \frac{H_{in} - H_{out}}{H_{in} - H_{is}} = \frac{\Delta H_{real}}{\Delta H_{is}} \quad \mathbf{(7)}$$

Isentropic efficiency (η_{is}) changes significantly with load, whereas mechanical efficiency is typically high (0.95 to 0.99) and changes over a narrow range [*10*]. With a known mechanical efficiency, the enthalpy of the exhaust steam can be calculated using Equation (8).

$$H_{out} = H_{in} - \frac{W}{\eta_{mech} \cdot m} \quad \mathbf{(8)}$$

Deaerators

Proper optimization of a steam network does not only involve turbines — other pertinent equipment, like deaerators, must also be considered in the model. A diagram of a typical deaerator is shown in Figure 5. Deaeration is the removal of dissolved gases, such as oxygen or carbon dioxide, from the treated water prior to its introduction into the boiler. Assuming a fraction of flash steam is lost in the vent, material and energy balances around the deaerator are given by Equations (9) and (10).

$$m_{DW} + m_{CR} + m_{SD} + m_{FS} = \alpha\left(m_{FS} + m_{SD}\right) + m_{BFW} \quad \mathbf{(9)}$$

$$m_{DW}H_{DW} + m_{CR}H_{CR} + m_{SD}H_{SD} + m_{FS}H_{FS} = \alpha\left(m_{FS} + m_{SD}\right)H_{vent} + m_{BFW}H_{BFW} \quad \mathbf{(10)}$$

Steam-condensate recovery

Steam-condensate recovery systems (Figure 6) are another crucial part

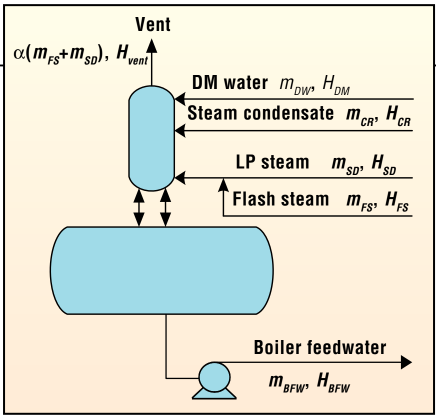

FIGURE 5. A deaerator removes dissolved gases from treated water before it enters a boiler

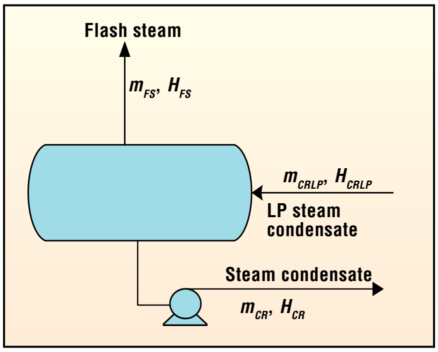

FIGURE 6. A steam-condensate recovery system usually consists of a flash drum and a pump

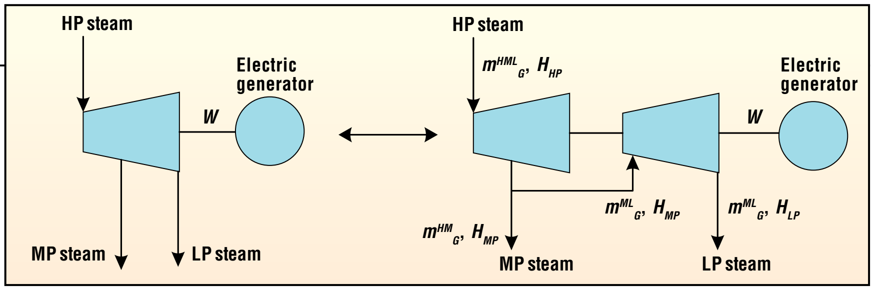

FIGURE 7. A steam-turbo generator generates electrical power that is useful for the facilities; here, it is represented as two back-pressure turbines in series

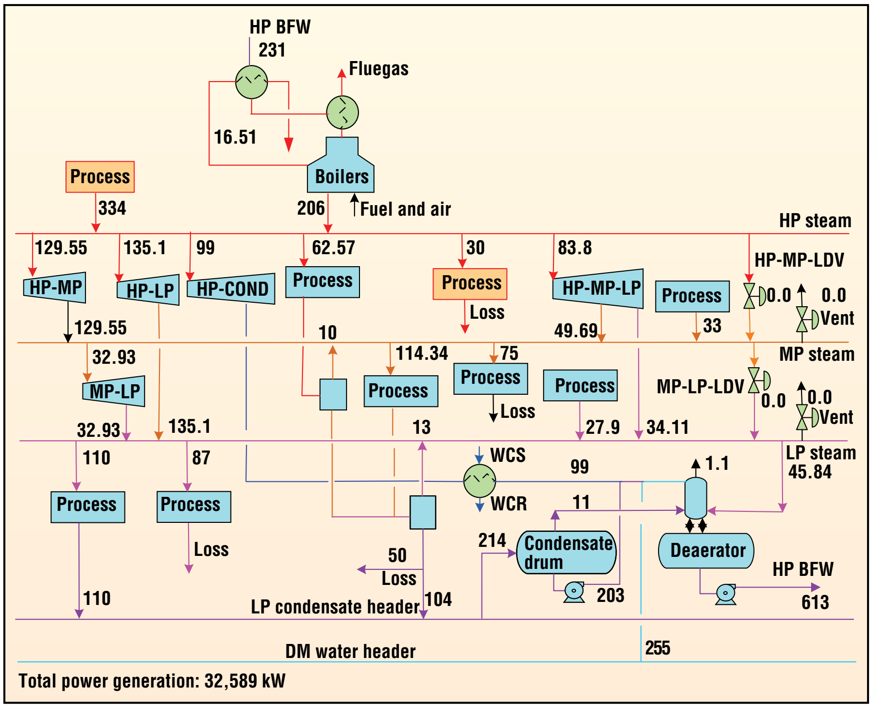

Figure 8. This diagram shows the steam network's base-case configuration. Data shown in the diagram are steam flowrates in metric tons per hour (m.t./h). HP-COND is the high-pressure steam condensate

of steam networks. Consisting of a flash drum and pump to separate the condensate and flash steam, these recovery systems must be taken into account for optimization. Material and energy balances around steam-condensate recovery systems are given by Equations (11) and (12).

$$m_{CRLP} = m_{CR} + m_{FS} \qquad (11)$$

$$m_{CRLP} H_{CRLP} = m_{CR} H_{CR} + m_{FS} H_{FS} \qquad (12)$$

Optimization model

Optimizing the operation of steam turbine drivers in refinery steam networks is a complex task, with many degrees of freedom, which requires continuous monitoring and adjustment according to changes in the operating scenarios. Although many types of models and optimization techniques are currently available [*6, 7, 10*], mixed-integer linear programming (MILP) offers robustness and reliability. Hence, the case study in this article is presented and solved using MILP. The example in this article describes the MILP formulation for a steam network with many steam-turbine drivers (both switchable and non-switchable) and a single steam-turbo generator.

The steam-turbo generator, which generates electrical power, can be modeled as a combination of HP-to-MP and MP-to-LP back-pressure turbines, as shown in Figure 7. The objective for the optimization of a given steam network is to maximize total power generation while considering the following constraints:

- Energy and material balances of the network
- Choice of switchable drivers for turbines or motors
- Variable steam flow through steam-turbo generators
- Capacity limitations of the selected steam turbines

Steam rate (SR) of a steam turbine is defined as the steam flowrate (kg/h) required per unit power produced (kW). It varies nonlinearly with the amount of steam flow (or power generated) due to variation in the steam turbine efficiency. However, this is not a problem for steam-turbine drivers as the power demand for the steady-state model is fixed and SR variation is negligible for small changes in steam flowrates. Hence, SR is used as a key parameter for the selection of efficient steam turbines. Steam flowrate through the steam-turbo generator can be varied during the optimization procedure. This requires a nonlinear model for predicting power, which leads to mixed-integer nonlinear programming (MINLP) formulation. It is very difficult to get a global optimum for such a model. However, the model can be converted into MILP formulation by using Equations (1), (2) and (3).

The cost of steam must also be considered. There are two approaches to estimate steam cost. The first method uses fuel pricing and enthalpy to estimate the cost of HP, MP, LP or flash steam. This second method estimates the cost of LP steam by subtracting the cost of power generated by the steam

TABLE 1. CAPACITY CONSTRAINTS FOR THE POWER GENERATOR

m_G^{HML}	≤	m_G^{HMLmax}
m_G^{HML}	≥	m_G^{HMLmin}
m_G^{HM}	≤	m_G^{HMmax}
m_G^{HM}	≥	m_G^{HMmin}
m_G^{ML}	≤	m_G^{MLmax}
m_G^{ML}	≥	m_G^{MLmin}
P	≥	$P_{basecase}$
These constraints must be satisfied for the steam-turbo generator's material balance		

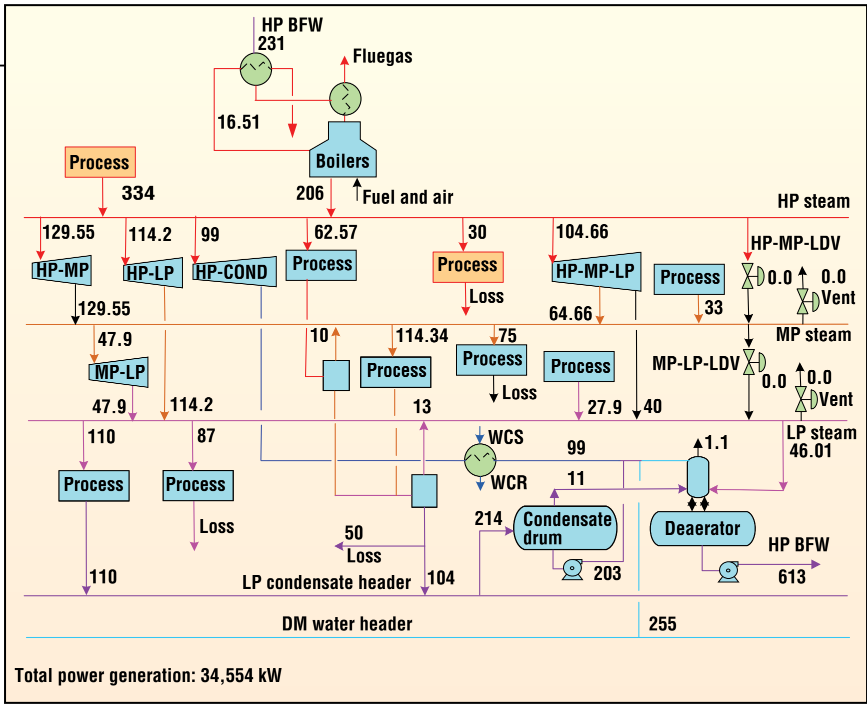

FIGURE 9. This diagram shows the optimized solution for the base-case network. Some of the steam flows (shown in m.t./h) between turbines were altered, and the resulting total power generation increased

turbines from the cost of HP or MP steam (estimated based on the cost of production). This method reflects the true value of steam at any level, and should be used to evaluate the true benefits of energy conservation projects [*10*]. Using this approach, for sites installed with cogeneration plants, LP steam cost can be negative.

Optimization objective

The base-case steam network for this optimization model is shown in Figure 8. It involves a total of 93 steam-turbine drivers: 35 HP to LP, 15 HP to MP, 3 HP to vacuum (condensing-type), 40 MP to LP steam turbine drivers and one steam-turbo generator. Out of these, 65 are switchable and 28 are non-switchable steam-turbine drivers. Steam generation and consumption amounts for the network are shown in Figure 8 [*12*]. The following assumptions were made in obtaining the optimum solution for the base case:

- Negligible pressure and temperature drops in the steam headers
- HP steam pressure of 43 bars and HP steam temperature of 3,600°C for the steam-turbine drivers and 3,800°C for the steam-turbo generator
- MP steam pressure of 11.5 bars
- LP steam pressure of 4.5 bars
- Total HP, MP and LP steam generation and consumption from process units are constant
- All the steam generated at MP and LP steam levels by the process units are at saturated conditions, corresponding to the header pressure
- The total boiler feed-water flowrate requirement for the base case and optimized case is assumed to be 102% of the total steam generation, accounting for overall blowdown
- Steam flowrates through the steam-turbine drivers are considered constant

TABLE 2. KEY PARAMETERS FOR OPTIMIZATION

Parameter	Base case	Optimized case
Steam turbo generator (HP-MP-LP) inlet flow, m.t./h	83.8	104.66
Steam turbo generator (HP-MP-LP) extraction flow, m.t./h	49.69	64.66
Steam turbo generator (HP-MP-LP) exhaust flow, m.t./h	34.11	39.99
Power from turbo generator, kW	6,435	8,375
Total power generation, kW	32,589	34,554
Total annual savings (compared to base case), $ (Note that total savings were calculated by assuming a power cost of $0.15/kWh and 8,760 annual operating hours)		2,581,883

The ultimate objective of this MILP optimization exercise is to maximize the total power generation from the base-case steam network. Here, power consists of the total shaft power from the steam turbine drivers and the electrical power from the steam-turbo generator. Equation (13) defines this objective function.

$$P = \sum_{i=1}^{p}\left(\frac{m_i^{HL}}{SR_i^{HL}}\right)Y_i^{HL} + \sum_{j=1}^{q}\left(\frac{m_j^{HM}}{SR_j^{HM}}\right)Y_j^{HM} + \sum_{k=1}^{r}\left(\frac{m_k^{HC}}{SR_k^{HC}}\right) + \sum_{l=1}^{s}\left(\frac{m_l^{ML}}{SR_l^{ML}}\right)Y_l^{ML} + \left(n^{HM}m_G^{HML} - W_{INT}^{HM}\right) + \left(n^{ML}m_G^{ML} - W_{INT}^{ML}\right) \quad (13)$$

In Equation (13), note that there are only three continuous variables (m_G^{HML}, m_G^{HM} *and* m_G^{ML}), but the number of binary variables is 65, one for each switchable turbine in the base-case scenario. These binary variables are defined as:

- Y_i^{HL} *for i = 1,…,p*
- Y_j^{HM} *for j = 1,...,q*
- Y_l^{ML} *for l = 1,…,s*

The binary variable, *Y*, is used for selecting the operating mode of a steam turbine. If its value is zero, the steam turbine is considered to be in stopped condition. If its value is one, the steam turbine is considered to be in operation [*12*]. Additionally, many constraints must be considered when evaluating Equation (13), including the steam material balances for the HP, MP and LP headers, given in Equations (14), (15) and (16), respectively.

$$m_{blr} + m_{HPG} = \sum_{i=1}^{p} m_i^{HL} + \sum_{j=1}^{q} m_j^{HM} + \sum_{k=0}^{r} m_k^{HC} + m_G^{HML} + m_{HPC} + m_{ld}^{HM} \quad (14)$$

TABLE 3. TRUE COST OF STEAM

Case	Base case	Optimized
Total power generated by HP-to-MP steam turbines, kW	8,720	10,368
Total steam flow through HP-to-MP steam turbines and steam-turbo generator, m.t./h	213	234
Total power generated by MP-to-LP, HP-to-LP steam turbines and steam-turbo generator, m.t./h	7,635	7,952
Total steam flow through MP-to-LP, HP-to-LP steam turbines and steam-turbo generator, m.t./h	202	202
HP steam cost, $/ton	27.48	27.48
MP steam cost after power generation credits from HP-to-MP, $/ton	21.35	20.84
MP steam cost after power generation credits from HP-to-MP and mixing saturated MP steam generation from process, $/ton	21.42	20.99
LP steam cost after power generation credits from MP-to-LP, $/ton	19.25	18.09
LP steam cost after power generation credits from MP-to-LP and mixing saturated LP steam generation form process, $/ton	19.59	18.63

$$m_{MPG} + m_{ld}^{HM} + m_G^{HM} + \sum_{j=1}^{q} m_j^{HM} = \sum_{l=1}^{s} m_l^{ML} + m_G^{ML} + m_{MPC} + m_{ld}^{ML} + m_v^{M} \quad (15)$$

$$m_{LPG} + m_{ld}^{ML} + m_G^{ML} + \sum_{l=1}^{s} m_l^{ML} + \sum_{i=1}^{p} m_i^{HL} = m_{LPC} + m_v^{L} \quad (16)$$

The material balance for the steam-turbo generator is defined in Equation (17).

$$m_G^{HML} = m_G^{HM} + m_G^{ML} \quad (17)$$

Constraints for this balance are given in Table 1. Other pertinent material balances were previously established in Equations (9) through (12).

Solving the problem

The solution to the MILP can be reached using commercial tools, such as Frontline's Premium Solver Pro, or Microsoft Excel's Solver. The resulting optimized network is shown in Figure 9. Key results, including affected steam flowrates, are summarized in Table 2. Most notably, the optimization exercise increased the total power generation from 32,589 kW to 34,554 kW, mainly due to improved efficiency in the steam-turbo generator.

The 1,965-kW energy savings demonstrated in this model translate into a financial benefit of over $2.5 million for the refinery. Table 3 shows a comparison of the true cost of steam in the base case and the optimized case. The true cost of MP steam is estimated by weighted-average costs of MP steam generated by HP-to-MP steam turbines, the steam-turbo generator and saturated MP steam generated at the process. Similarly, the true cost of LP steam is estimated by weighted-average costs of LP steam generated by HP-to-LP steam turbines, MP-to-LP steam turbines, the steam-turbo generator and saturated LP steam generated at the process. The true value of steam is essential for benefit analyses of energy-conservation projects.

In conclusion, significant energy savings can be realized by optimizing steam-turbine driver selection and operation in a steam network. The optimized scenario presented in this article is quite attractive economically, as it improves energy efficiency while remaining physically sound. This article mainly focuses on key requirements and benefits in a typical case; economic benefits outlined in this study may vary from site to site. ■

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Author

C. Chandra Sekhara Reddy is a part-time Ph.D. scholar at Andhra University (Visakhapatnam, India 530003; Phone: +65 98624720; Email: cs6_reddy@yahoo.co.in). He received B.S.Ch.E. and M.S.Ch.E degrees from Andhra University and IIT Kanpur, respectively. He has more than 17 years of process design and operations experience in the petroleum refinery, petrochemical and chemical industries. Reddy has been with Singapore Refining Co., Pvt. Ltd. since 2007. He is currently working as the lead process design engineer. He also worked in several positions at Celanese Singapore Pte. Ltd., SUT Singapore Pte. Ltd., The Polyolefin Co. (Singapore) Pte. Ltd. and IPCL, India. His research interests are in process design and energy efficiency improvement of process systems.

G.P. Rangaiah has been with the National University of Singapore (21 Lower Kent Ridge Rd., Singapore 119077; Phone:+65 6516 2187; Email: chegpr@nus.edu.sg) since 1982, and is currently professor and deputy head for student and academic affairs in the Dept. of Chemical & Biomolecular Engineering. He received B.S., M.S., and Ph.D. degrees from Andhra University, IIT Kanpur and Monash University, respectively. Rangaiah worked in Engineers India Ltd. for two years before his doctoral study. His research interests are in control, modeling and optimization of chemical, petrochemical and related processes. He has supervised ten research fellows and 35 graduate theses. He has edited four books, published more than 150 papers in international journals and presented 110 papers in conferences. Rangaiah has received several teaching awards, including the Annual Teaching Excellence Awards from the National University of Singapore for four consecutive years.

S.V Naidu has been with the Andhra University (Visakhapatnam, India 530003; Phone: +91 0891-2844893; Email: profnaidu90@gmail.com) since 1990, and is currently professor in the Dept. of Chemical Engineering and Dean, Planning and Resource mobilization at AU College of Engineering. He received a B.S. degree in science from Kakatiya University, B.S. and Ph.D. degrees in chemical engineering, from Andhra University, and also a M.S. degree from R.E.C., Warangal. His research interests are in heat transfer, PEM fuel cells and reactive distillation. Prof. Naidu has supervised six research fellows and 23 graduate theses. He has published 23 papers in national and international journals and presented 11 papers in conferences.

References

1. Bloch, H.P., Singh, M.P., "Steam Turbines Design, Applications and Re-Rating", 2nd edition, McGraw-Hill, 2009.
2. Branan, C. R., "Rules of Thumb for Chemical Engineers — A Manual of Quick, Accurate Solutions to Everyday Process Engineering Problems", 4th Edition, Elsevier, 2005.
3. Fleming I., Optimizing steam systems: Part II, *PTQ* (Petroleum Technology Quarterly), Q3 2010, pp. 54–62.
4. Lieberman, N.P., "Process Engineering for a Small Planet, How to Reuse, Re-Purpose and Retrofit Existing Process Equipment", John Wiley, 2010.
5. Lieberman, N.P., Lieberman E.T., "A Working Guide to Process Equipment", 3rd edition, McGraw Hill, 2008.
6. Mavromatis, S.P., Kokossis, A.C., Conceptual Optimization of Utility Networks for Operational Variations - I. Targets and Level Optimization, *Chem. Eng. Science*, Vol. 53, No. 8, pp. 1,585–1,608, 1998.
7. Micheletto, S.R., Pinto, J.M., Operational Optimization of the Thermoelectric System of an Oil Refinery, 16th European Symposium on Computer Aided Process Engineering and 9th International Symposium on Process Systems Engineering, Elsevier, 2006.
8. Radle, J., The Importance of Intensive Steam Trap Management, *Chem. Eng.*, Nov. 2007, pp. 40–47.
9. Risko, J. R., Handle Steam More Intelligently, *Chem. Eng.*, Nov. 2006, pp. 38–43.
10. Smith, R., "Chemical Process Design and Integration", 2nd edition, John Wiley, 2005.
11. Tanthapanichakoon, W., Saving Energy in Multilevel Steam Systems, *Chem. Eng. Progress*, Jan. 2012, pp. 27–32.
12. For more information, see Tables 4–8 in the online version of this article.

Editor's Note: For additional information, tables and graphics, see the online version of this article.

Gear Units In CPI Plants

FIGURE 1. In this conventional, double-helical gear unit (with a welded-steel casing), double-helical gears are used to minimize the axial load (that is, the load in the direction of the shaft). The complex casing was fabricated by welding

Follow this guidance to improve the selection and operation of gear units in CPI plants

Amin Almasi
Rotating Equipment Consultant

Gear units play a critical role in a diverse array of chemical process industries (CPI) facilities, to match the speed of a selected driver with the speed of the driven equipment. Today, they are used extensively in pumps, turbines and compressors, in material-handling units (such as conveyers and stackers), and in other equipment, including mixers, kneaders and extruders.

This article discusses high-power, high-speed gear units for large rotating machines and material-handling systems. These gear units can be used in the power range of 0.1–100 MW, with gear tip speeds usually between 20–200 m/s. The American Gear Manufacturers Assn.'s (AGMA) "Specification for High Speed Helical Gear Units (6011)" covers different aspects of high-speed gear units, such as the gear rating, lubrication, vibration, testing and others.

Large, high-speed gear units for CPI applications are usually comprised of case-hardened, double-helical gear-teeth in welded-steel casings (Figure 1). The gear shafts are supported by modern bearings (typically plain bearings for low speeds). Ideally, bearing forces should be symmetrical with no tilting moment, to ensure minimum axial load (the force in the direction of the shaft).

Practical notes on gear units

As is often the case, engineers tend to focus their attention on the driver and the driven equipment, so the gear unit(s) often receive virtually no attention. However, the client, the vendor, and the gear-unit subvendor should all pay considerable attention to the following aspects of gear units:

- Gear-set design, such as gear teeth details
- Gear-unit loading (loads on the gears and shafts) and analysis
- Material selection
- Heat-treatment options
- Fabrication and assembly
- Gear-unit lubrication
- Quality and testing
- Commissioning

A proper helix angle (the angle between the axis of a helical gear and an imaginery line tangent to the gear tooth) — in the range of 10–30 deg — should be used for the gear teeth. This will provide suitable operation and will considerably reduce the axial forces.

Within that range, a relatively large helix angle (in the range of, say, 22–30 deg, compared to 10–18 deg), can result in a high contact ratio, which could offer better performance, smoother operation and lower noise and vibration. The contact ratio is the ratio of face advance to the circular pitch. This ratio defines how many teeth are in contact at all times (on average).

Gear-unit arrangement

Several ways of integrating a gear unit into a CPI machinery train are discussed below:

Option 1. In this option, the driver, the gear unit and the driven equipment are all installed separately. Due to thermal expansions or different mechanical loads, the shafts could displace in the plane perpendicular to the axial direction of each shaft (known as radial shifts). If relatively large radial shifts occur between each equipment shaft and the gear unit shafts, a double-jointed coupling is needed, to allow for some movement between shafts. This depends on thermal expansions, mechanical displacements and other design and operation decisions.

Option 2. In the second arrangement, the driver is attached directly to the gear-unit housing. In this scenario, because the driver and the gear unit both display sufficiently low axial and radial displacements, the coupling (or shaft extension) between the driver shaft and the gear-unit input shaft could be omitted. The driven equipment is mounted separately and connected to the gear unit with a coupling. This coupling is necessary because the different heat-induced expansions of the gear unit and the driven equipment can cause relative shifts in the shaft positions.

Option 3. In the third design, the gear unit is directly connected to the driven equipment, in anticipation that no radial or angle shifts can occur. In this scenario, no coupling joint is required between the gear unit and the driven equipment. Figure 2 shows an example of a complex gas turbine coupled to a gear unit (for the speed match).

Planetary gear units

The most commonly used special-purpose gear-unit designs include different models of double-helical gear units. However, planetary gear units can often be employed in high-speed CPI machinery (typically in the 0.2–30 MW range). These are popular both for rotating machines and material-handling units, particularly where large speed ratios are necessary.

While double-helical gear units are simple and popular, planetary gear units offer smaller size and higher efficiency compared to other types of gear units. Because the transmitted power is divided over several tooth meshes, planetary gear units are more compact and less expensive than other options.

The smaller gear diameters in a planetary gear unit also produce smaller mass moments of inertia, and this substantially reduces the acceleration and deceleration torque during acceleration and braking. Generally, high speed ratios can be achieved (even 80 or more). The coaxial design permits a superior arrangement for many CPI machineries. However, due to operational issues and reliability risks, planetary gear units will require extra consideration.

Figure 3 shows an example of a planetary gear unit. They can achieve a large speed ratio (even 40 to 80) in a very compact unit.

A planetary gear unit typically consists of three coaxially rotating components: a sun gear, a carrier with several planetary gears, and a ring gear. Among the variants of planetary gear units, the options preferred for CPI applications are:

- The star-gear type, with speed ratios of around 2–12
- The planetary-gear type, with speed ratios of roughly 3–13
- The star-gear type with the double planet, with speed ratios of around 12–40
- The compound-epicyclic gear type, with speed ratios of about 8–80

The star-gear type and the planetary-gear type can usually offer a similar ratio range (both can cover a speed ratio in the range of 3–12). The star-gear type is used when the rotating carrier would cause unacceptably high pressure on the bearing journal. The compound-epicyclic gear type offers one of the most compact options.

An important loss in a high-speed gear unit is windage loss, which represents the power lost because of the compression of the air-lubricant mixture around teeth roots during meshing and the aerodynamic trail of the teeth in the air-lubricant mixture. With any planetary-gear type, it is necessary to take into account a relatively high windage.

The best operation and performance occurs when the load is distributed as evenly as possible across the individual planet gears. An uneven load balance can create damaging effects.

The ability to reduce friction can, theoretically, result in a better-centered gear-tooth loading. However, in real-life scenarios, some friction (and thus some unbalances in the loading) should be expected. The mass inertia of the gear-unit elements can also offer some dynamic loads. It is desirable to reduce the masses, but there are always practical limits in the mass-reduction exercises (some limits to achieve very lightweight designs)

The partial-load operations and particularly the minimum-load case, can offer some challenges. The no-load case occurs when the gear unit and the associated machinery train are operating with no load — for example, when a pump unit operates in the pre-commissioning stage without actually pumping a liquid, and thus, the driven gear unit just rotates with no load transmission. Some machinery trains should only operate a very short time in a no-load condition, otherwise damage or reliability issues may arise.

Usually, most gear units have several backlash-prone joints and relatively large masses that are unable to center themselves when the load changes, and this may cause a gear unit to behave unstably. This issue needs considerable attention, especially for planetary gear units. For instance, sophisticated elastic mountings are usually used for the planetary gears (for example, in the form of flex pins). These will bend under a load, with the result that the planet gears do not skew but are simply minimally displaced parallel to the pinion or ring-gear axis. This solution can ensure an optimum load balance between the meshed teeth and the even load distribution across the entire width of the tooth face at both full and partial load.

Tognum

FIGURE 2. Gas turbines typically have a defined operating speed range. When used in a machinery train (with a generator, compressor or pump train), a well-designed gear unit is used to match the speed of the turbine shaft to the driven equipment

Selection criteria

Key factors influencing the choice of gear units are load capacity, efficiency, and successful references (for comparable applications). In general, several types of gear types are available for planetary gear-units, including spur gears, single-helical gears, double-helical gears and others. If single helical gears are used, the two opposing axial forces acting on the planetary gear may generate a large tilting moment (axial bearings could be required if the helix angle is not selected properly).

The double-helical gear set usually requires free axial adjustability to allow users to achieve an even load distribution across the two tooth halves. However, the two gear meshes can prevent the necessary movement (see Figure 1). In this way, two side-by-side gear meshes do not allow for the tiny movements required for adjustments and smooth operation. In addition, external axial forces may interfere with the load distribution.

Spur gears (or straight-cut gears) are the simplest type of gear. Their slightly better efficiency compared to the spur gearing is one advantage for the helical gearing. For planetary gear units, a single-helical gearing with an optimum helix

FIGURE 3. In this planetary gear unit, the transmitted power is divided over several teeth. Planetary gear units are smaller, more compact and cheaper than their conventional counterparts

angle is commonly used (Figure 3).

In some cases, the CPI machinery shaft could be connected rigidly (without a coupling) to the planetary gear-unit shaft. In other designs, the machinery bearing can be incorporated in the planetary gear-unit housing. As a result, the different heat-induced expansions of the gear unit and that of the machinery housing would produce no radial shift. However, this could cause an angle error between the rotor and ring-gear axis. This can be absorbed by a single-jointed coupling.

Gear-unit reliability

Failures on gear units are usually related to teeth breakage and damage to the tooth flanks (these often result from impact or fatigue fractures, wear or pitting). Having sufficient lubrication and maintaining the overall surface condition (particularly the roughness) of the tooth flanks are important. Sufficient lubricant film on the gear flanks can minimize the impact of pitting and micro-pitting. Cracks (particularly friction cracks) and erosions can also cause gear-unit failures.

Fractures can occur in areas of high stress concentrations, which can result from abrupt changes in the geometry, localized areas of high strain (particularly bending deformations) or regions experiencing thermal extremes. Reliability and performance calculations (such as the gear-unit rating, gear tooth-bending strength, gear surface pitting, scuffing and others) should be carefully reviewed.

The fabrication method also has a great influence on reliability and gear failure modes. Pinions are always made from one-piece fabrication, which is generally more reliable than other options.

Shrink fitting is a technique in which an interference fit is achieved by a relative size change after assembly. This is usually achieved by heating or cooling one component before assembly and allowing it to return to the ambient temperature after assembly, employing the phenomenon of thermal expansion to make a joint.

The shrink-fit design for the gear wheel is usually limited by the influence of centrifugal forces. For instance, the gear-unit codes do not accept the shrink-fit design for pitch-line velocities of over 140 m/s. In those cases, the one-piece version should be applied. In this configuration, the gear wheel and its shaft are in one piece. In gear units for rating powers of more than 20 MW, the one-piece design usually requires a large forging with a great weight. Manufacturing large special-purpose gear units requires access to special forging shops for very large, one-piece components.

The gear wheel shaft can be either solid or hollow. Because of a better hardenability (during manufacturing), the hollow-shaft design is often preferred.

Material selection and metallurgical issues are very important for any gear unit. Case-hardening-grade gear materials are widely used. Case hardening (or surface hardening) is the process of hardening the surface of the gear while allowing the metal beneath the surface to remain soft, thereby forming a thin layer of harder metal (the case) at the surface.

Two important subjects for gear units deserve special attention for optimal performance and reliability:

1. Tooth adjustments and corrections. The prediction of mechanical and thermal deformations and adjustments on the tooth dimensions (such as tooth height and width) is essential.

2. Heat treatment. Heat treatment involves the use of heating or chilling, normally to extreme temperatures, to achieve a desired result mostly the hardening of the gear material. For gears, carburizing heat-treatment or nitriding heat-treatment are commonly employed.

There is one potential problem that every engineer working with gear units should be aware of. This should be considered in the design and manufacturing stage. To achieve the most-even load distribution possible, adjustments (also called corrections) are usually necessary in the direction of the tooth height and the tooth width. Because the pinion gets hotter than the gears, the pinion's base circle and base pitch could expand more. During manufacturing in a cold condition (say ambient conditions), the pinion has to be made with a pitch that has been reduced by a difference (an adjustment) because of the thermal expansion. The increase in the pitch of the rotating gear as a result of the centrifugal force should also be taken into account during the manufacturing.

The heat is distributed unevenly across the width of the tooth face, resulting in uneven expansion of the gear body. Asymmetrical adjustment techniques should be used for better corrections and consequently smoother gear unit operation. In simple terms, these techniques depend on the accurate prediction of asymmetrical thermal movements and the required asymmetrical adjustments to achieve a perfect match and smooth operation during actual operating situations.

Suitable profile adjustments (corrections) can be employed by the gear unit vendor to minimize the dynamic loads and the gear unit noise. These adjustments, if implemented properly, can considerably reduce mesh impacts and shock loads at both the beginning and the end of meshing (and the transitions from single to double meshing). These corrections can also help to achieve uniform transmission of the rotary movement, despite a position-dependent tooth deformation.

Heat-treatment options

For critical gear units, carburizing heat-treatment or nitriding heat-treatment are commonly used by vendors. Case hardening (in the usual form of carburizing heat-treatment or nitriding heat-treatment) could be considered an economic solution, since it allows a good range of adjustments to the desired hardness depth of the gear.

These manufacturing and heat-treatment options offer one of the highest values to ensure long-term resistance to pitting and tooth flexure. Selection of the most appropriate option depends on many factors, such as the application (speed, power, operating details and others) and many other technical and commercial issues.

Carburizing usually improves fatigue resistance. With better fatigue-resistance and better strength, the carburized gears need relatively lower thicknesses and materials and thus gear dimensions can be better optimized. As a result, carburized components can theoretically be designed smaller compared to the nitride-hardened ones.

However, care should be taken when selecting carburizing. Distortions of the components during quenching can result in some residual stresses. By comparison, nitriding is a relatively low-distortion hardening method. With nitriding, the whole heat-treatment process is carried out below the transformation temperature (that is, the temperature where a metallurgical phase transformation occurs). However, only small hardness penetration depths can be obtained using this method. For instance, 0.4–0.7 mm with normal nitriding steels, while this depth could be up to 1.5 mm with special steels. Meanwhile, nitrided surfaces are usually harder and could show more brittleness in case of shock strains compared to carburized ones. Also, the damage curve in the fatigue strength for the finite life in nitrided gears tends to be flat compared to that of carburized ones. These factors can influence the rating of gears for startup, the shock loading the short-circuit torque (for gear units connected an electric machines) and other transient situations.

It has been proven that the residual stresses can influence the total strain of the gear sets. In the case of carburizing, residual stresses can be relatively high. An advantage of nitriding is that the inner residual stresses are relatively low. ■

Edited by Suzanne Shelley

Author

Amin Almasi is a rotating equipment consultant in Australia (Email: amin.almasi@ymail.com). He previously worked at Worley Parsons Services Pty Ltd. (Brisbane, Australia), Technicas Reunidas (Madrid, Spain) and Fluor (various offices). He holds chartered professional engineer license from Engineers Australia (MIEAust CPEng – Mechanical), chartered engineer certificate from IMechE (CEng MIMechE), RPEQ (Registered Professional Engineer in Queensland) and he also holds M.S. and B.S. in mechanical engineering. He specializes in rotating machines including centrifugal, screw and reciprocating compressors, gas and steam turbines, pumps, condition monitoring and reliability. Almasi is an active member of Engineers Australia, IMechE, ASME, Vibration Institute, SPE, IEEE, and IDGTE. He has authored more than 60 papers and articles dealing with rotating machines.

Fractionation Column

Corrosion: the silent killer

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

CUI — that acronym should be enough to capture your attention. All chemical process industries (CPI) plants are aging — and some are aged, especially in the U.S. and Europe. Corrosion under insulation (CUI) should be regarded as a silent killer, and there aren't enough doctors, or in other words, experts in the field to address the problem sufficiently.

FRI's experimental unit was constructed in 1953 in Alhambra, Calif. In 1990, the unit was moved to Stillwater, Okla. The columns, heat exchangers, vessels and piping function at pressures from 10 mm Hga to 500 psia. Most of the equipment is comprised of carbon steel. Some of that equipment is over 50 years old.

FRI's low-pressure kettle reboiler was well insulated. Holes in the metal wrappings were used for regular UT (ultrasonic thickness) inspections by certified technicians. Historically, none of those readings ever caused concern. In 2011, a large portion of that reboiler was stripped of its insulation (when FRI added windows to that reboiler). The underlying steel shell looked great. In 2013, another large portion of that reboiler was stripped (when FRI added two more windows and borescope nozzles). This time, the story was different. This time, troublesome surface rusting was observed.

In retrospect, this section of the reboiler might have been the focal point for rainwater dripping from the deck above. The entire reboiler was stripped of its insulation. Many UT readings were taken by both an FRI technician and a contract certified technician. There was just one small area where the metal thickness was approaching the minimum allowed. In response, the bundle was pulled and the reboiler shell was entered. Deep in the shell, past the liquid-product overflow baffle, deep dimples were found in the bottom of the shell. Weld overlay work was effected by an R-stamp welder. The reboiler was hydrotested twice and it held high pressures both times. Nevertheless, a new shell was ordered. The lesson learned is that sometimes, when possible, vessels need to be totally stripped and fully entered.

At the September ChemInnovations conference in Galveston, Tex., Russ Davis, of Mistras Group, gave an excellent presentation regarding CUI. He bemoaned the fact that too many U.S. companies do not have complete and fully functional CUI and insulation replacement programs. He described how even stainless-steel vessels and piping can be affected by CUI — in the U.S. Gulf Coast region due to chlorides present in the atmosphere. He listed the equipment and piping that are particularly prone to CUI: areas exposed to mist from cooling towers; dead legs; pipe hangers; vibrating pipes; bottoms of horizontal lines; hardened caulking; missing insulation plugs and others. Davis provided the ChemInnovations attendees with an exhaustive list of NDE (non-destructive evaluation) methodologies, listing their advantages and disadvantages. Some of those technologies only identify wet insulation. Some identify corrosion areas, but they do not provide shell- or pipe-thickness data.

Ultimately, Davis drew the exact same conclusion that the FRI staff drew: sometimes, vessels need to be totally stripped and fully entered. ■

Mike Resetarits

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Andorra, France, Gibraltar, Greece, Israel, Italy, Portugal, Spain

Rudy Teng
Sales Representative
Chemical Engineering;
8F-1 #181 Wulin Road
Hsinchu 30055 Taiwan
Tel: +86 13818181202, (China),
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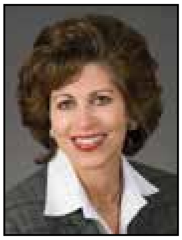
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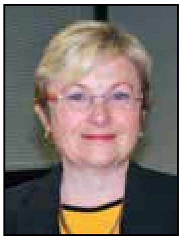
Wiseman

Environmental Drilling Solutions (Lafayette, La.) names *John Meckert* CEO, and *John Marty III* business development manager.

Specialty chemicals company **Evonik Canada, Inc.** (East Gibbons, Alta.), names *Diana Dascalescu* manager of the company's Maitland, Ont., site.

Jacqueline Hinman becomes CEO of **CH2M Hill** (Denver, Colo.), replacing *Lee McIntire,* who will step down in January. McIntire will continue to serve as chairman of the the board.

Wolfram Kreisel becomes managing director of **Kreisel GmbH & Co. KG** (Krauschwitz, Germany).

Paul Krauthauser becomes senior vice president, sales and marketing, and *Sherri Leonard* becomes vice president, portfolio strategy, at **Rising Pharmaceuticals**, a subsidiary of Aceto Corp. (Port Washington, N.Y.)

Rene Aldana becomes the managing director of Yokogawa Canada, Inc., a division of **Yokogawa Corp. of America** (Newnan, Ga.), overseeing all Yokogawa business operations in Canada.

Lorraine Wiseman becomes president and general manager of **Spirax Sarco** (Blythewood, S.C.), a supplier of fluid-control and steam systems.

Engineering, architecture and environmental consulting company **GHD** (Melbourne, Australia) appoints *Michael Muntisov* to the position of global technical leader for water. ■

Suzanne Shelley

BUSINESS NEWS

PLANT WATCH

Chandra Asri and Michelin partner on synthetic-rubber manufacturing plant

November 11, 2013 — PT Chandra Asri Petrochemical Tbk (Jakarta, Indonesia; www.chandra-asri.com) and Compagnie Financière Michelin have formed a partnership for the inauguration of a synthetic-rubber plant. Construction of the plant is planned to begin in early 2015, with completion and startup targeted at the beginning of 2017.

Mitsui Chemicals expands polypropylene capacity in North America

November 8, 2013 — Mitsui Chemicals Group (Tokyo; www.mitsuichem.com) and Prime Polymer, a Mitsui Chemicals subsidiary, have announced expansions to polypropylene production in the U.S. and Mexico, to meet the growing demands of the automotive sector. The U.S. expansion will increase production from 254,000 metric tons per year (m.t./yr) to 289,000 m.t./yr. The expansion in Mexico will increase production from 45,000 m.t./yr to 83,000 m.t./yr.

Chemtura dedicates new plant for urethanes and petroleum additives

November 7, 2013 — Chemtura Corp. (Philadelphia, Pa.; www.chemtura.com) has opened its new multipurpose manufacturing facility in the Nantong Economic and Technological Development Area in Nantong, China. The facility, located in Jiangsu Province, consists of three production units, including ones for petroleum additives and urethane products.

Solvay to build large-scale alkoxylation facility in Texas

November 6, 2013 — Solvay S.A. (Brussels, Belgium; www.solvay.com) says it will build and operate a large-scale alkoxylation unit in Pasadena, Tex., at a facility of LyondellBasell's Equistar Chemicals affiliate. Equistar will supply the ethylene oxide raw material to the unit, which is expected to be operational in 2015. Solvay will invest nearly €40 million in the endeavor.

Sibur launches new polypropylene-film production facility

November 6, 2013 — Sibur Holding's (Moscow; www.sibur.com) subsidiary Biaxplen has launched a new production facility for biaxially oriented polypropylene (BOPP) films. The new facility is located on the site of Sibur's Tomskneftekhim plant, which is the company's main polypropylene supplier. The BOPP production line has a nameplate capacity of 38,000 m.t./yr.

Evonik starts up new production facility in Shanghai for organic surfactants

October 29, 2013 — Evonik Industries AG (Essen, Germany; www.evonik.com) has opened a new production facility for organic specialty surfactants in the Shanghai Chemical Industry Park in Shanghai, China. The new facility has a capacity of around 80,000 m.t./yr.

AkzoNobel opens new plant in India for decorative paints and coatings

October 29, 2013 — AkzoNobel (Amsterdam; www.akzonobel.com) has opened a new €20-million decorative paints plant in Gwalior, India, which will have a capacity of 55 million L/yr. The factory has sufficient infrastructure in place to support future expansion plans.

WorleyParsons awarded detailed EPCM contract by Invista

October 24, 2013 — Invista (Wichita, Kan.; www.invista.com) has awarded WorleyParsons Ltd. (www.worleyparsons.com) an engineering, procurement and construction management (EPCM) contract for the development of a new hexamethylene diamine (HMD) plant at Shanghai Chemical Industrial Park. The plant will produce 215,000 m.t./yr of HMD. Production is scheduled to commence in 2015.

Black & Veatch selected for desalination project at world's largest copper mine

October 23, 2013 — Black & Veatch (Overland Park, Kan.; www.bv.com) has been selected for the the engineering design, procurement, field inspection and pre-commissioning for the marine and desalination elements of the $3.43-billion Escondida Water Supply project in Chile, which will deliver 57 million gal/d of water to Escondida, the world's largest copper mine.

Albemarle expands antioxidant manufacturing capabilities in China

October 22, 2013 — Albemarle Corp. (Baton Rouge, La.; www.albemarle.com), has completed installation of a granulation and blending system in Shanghai, increasing Albemarle's antioxidant capacity to over 10,000 m.t./yr. With these expansions, the facility can now produce non-dusting antioxidants in both granules and pellets.

MERGERS AND ACQUISITIONS

Asahi Glass to acquire interest in Vietnamese PVC producer

November 6, 2013 — Ashai Glass Co., Ltd. (AGC; Tokyo, www.agc.com) has reached an agreement with Petronas Chemicals Group Berhad (Kuala Lumpur, Malaysia; www.petronaschemicals.com) under which AGC will acquire a 78% equity stake in Vietnamese polyvinyl chloride (PVC) company, Phu My Plastics & Chemicals Co., Ltd. With this acquisition, AGC's global PVC capacity will be 650,000 m.t./yr, which is more than double the current capacity.

AEA Investors to acquire Siemens Water Technologies for €640 million

November 6, 2013 — AEA Investors LP (www.aeainvestors.com) has agreed to acquire Siemens Water Technologies (Alpharetta, Ga.; www.water.siemens.com) for €640 million. Under AEA, the company will continue its focus on equipment and services for municipal and industrial water- and wastewater-treatment.

Innospec expands oilfield chemicals presence by acquiring Bachman Services

November 5, 2013 — Innospec Inc. (Littleton, Colo.; www.innospec.com) announced that it has acquired Bachman Services Inc. and its affiliated companies from its private owners. Bachman, based in Oklahoma City, Okla., provides chemicals and services for the oil-and-gas industry.

Chevron Phillips completes sale of polystyrene business

October 31, 2013 — Chevron Phillips Chemical Company LLC (The Woodlands, Tex.; www.cpchem.com) has finalized the sale of its affiliate company, Chevron Phillips Chemical (China) Co. Ltd., to Grand Astor Limited. The sale includes a polystyrene plant in Zhangjiagang, China.

Ametek acquires 3-D technology expert Creaform for $120 million

October 29, 2013 — Ametek, Inc. (Berwyn, Pa.; www.ametek.com) has acquired Creaform, Inc., a developer and manufacturer of portable 3-D measurement technologies and a provider of 3-D engineering services for approximately $120 million. Based near Québec City, Canada, Creaform has annual sales of approximately $52 million. ■

Mary Page Bailey

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

December 2013; VOL. 120; NO. 12

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2011 — 2012 — 2013

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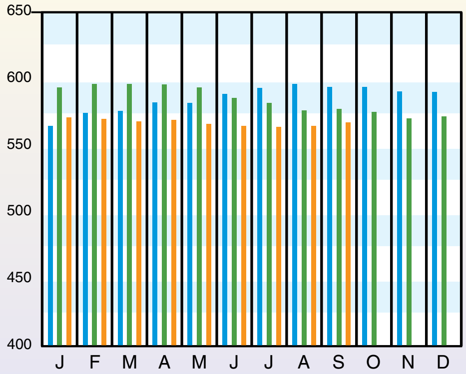
CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957–59 = 100)	Sept.'13 Prelim.	Aug.'13 Final	Sept.'12 Final
***CE* Index**	567.3	564.8	577.4
Equipment	686.2	682.8	700.8
Heat exchangers & tanks	618.3	615.8	643.9
Process machinery	654.7	653.1	662.3
Pipe, valves & fittings	875.3	871.2	895.7
Process instruments	411.4	410.7	424.0
Pumps & compressors	924.3	920.7	929.0
Electrical equipment	513.7	513.0	510.6
Structural supports & misc	747.1	736.3	742.3
Construction labor	321.8	320.9	324.8
Buildings	533.4	531.8	527.2
Engineering & supervision	325.1	325.1	328.7

Annual Index:

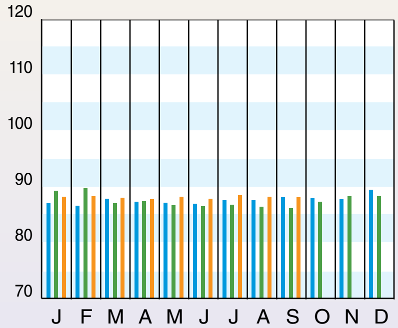
2005 = 468.2
2006 = 499.6
2007 = 525.4
2008 = 575.4
2009 = 521.9
2010 = 550.8
2011 = 585.7
2012 = 584.6



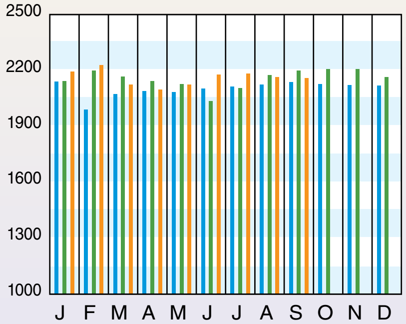
CURRENT BUSINESS INDICATORS*

	LATEST		PREVIOUS				YEAR AGO	
CPI output index (2007 = 100)	Sep.'13	= 88.1	Aug.'13	= 88.2	Jul.'13	= 88.5	Sep.'12	= 86.1
CPI value of output, $ billions	Sep.'13	= 2,160.0	Aug.'13	= 2,164.9	Jun.'13	= 2,179.2	Sep.'12	= 2,199.7
CPI operating rate, %	Sep.'13	= 74.4	Aug.'13	= 74.6	Jul.'13	= 74.9	Sep.'12	= 73.4
Producer prices, industrial chemicals (1982 = 100)	Sep.'13	= 299.9	Aug.'13	= 301.0	Jul.'13	= 299.6	Sep.'12	= 299.4
Industrial Production in Manufacturing (2007 = 100)	Sep.'13	= 96.0	Aug.'13	= 95.9	Jul.'13	= 95.4	Sep.'12	= 93.6
Hourly earnings index, chemical & allied products (1992 = 100)	Oct.'13	= 156.6	Aug.'13	= 156.8	Jul.'13	= 156.3	Oct.'12	= 154.9
Productivity index, chemicals & allied products (1992 = 100)	Sep.'13	= 105.7	Aug.'13	= 105.8	Jul.'13	= 105.2	Sep.'12	= 104.4

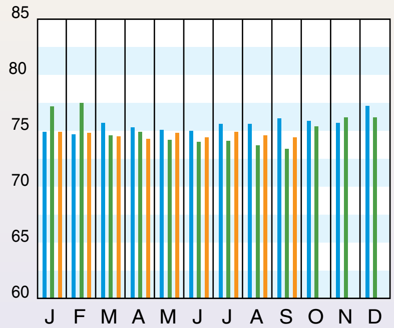
CPI OUTPUT INDEX (2007 = 100)



CPI OUTPUT VALUE ($ BILLIONS)



CPI OPERATING RATE (%)



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

CURRENT TRENDS

Preliminary data for the September 2013 *CE* Plant Cost Index (CEPCI; top; the most recent available) indicate that costs rose in all subcategories compared to the previous month, except the Engineering & Supervision category, which remained unchanged. The current CEPCI value stands at 1.75% lower than the value from a year ago. The year-over-year gaps have been narrowing over the past six months. Meanwhile, updated values for the Current Business Indicators from IHS Global Insight (middle) generally also saw small decreases in most indices. For example, the CPI output index, CPI value of output and producer price index all fell slightly from the previous values. ■

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