CHEMICAL ENGINEERING

February 2010

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Energy Audits

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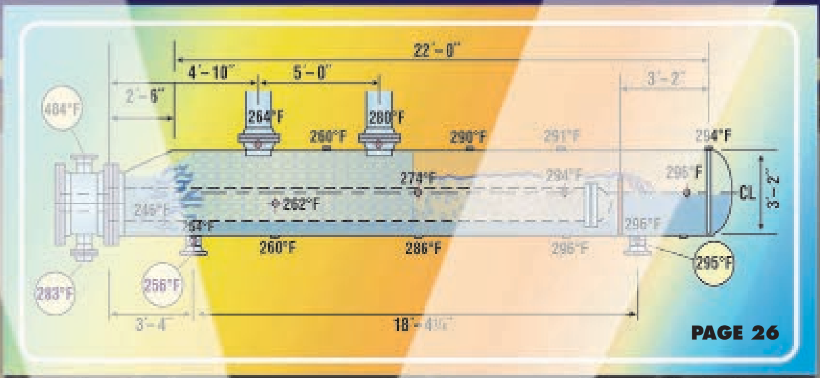
THAT'S ENTRAINMENT



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"A TROUBLE-SHOOTING REVELATION FOR OUR PLANT AND YOURS"

Milton Chaves — Hess Corp.

"PROOF THAT KETTLE REBOILERS CAN BEHAVE LIKE THERMOSIPHONS"

Henry Kister — Fluor Corp.

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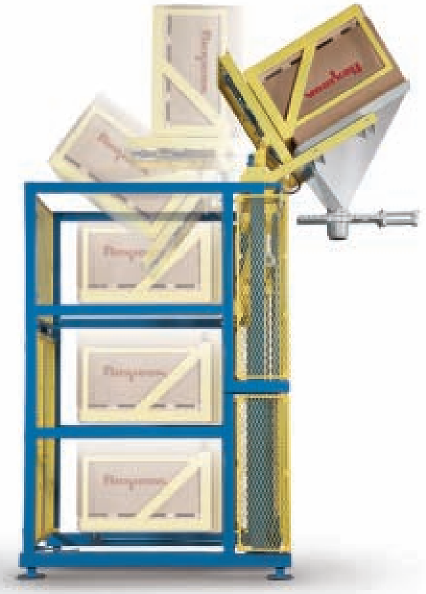

New TIP-TITE™ High-Lift Box/Container Dumper (shown) and Drum Dumper discharge into vessels 6 to 10 ft (183 to 305 cm) high, dust-free

TIP-TITE™ Dumpers bring newfound efficiencies and cost savings to the age-old task of dumping bulk materials from drums, boxes and containers, redefining this class of everyday plant equipment

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4 Cut cost

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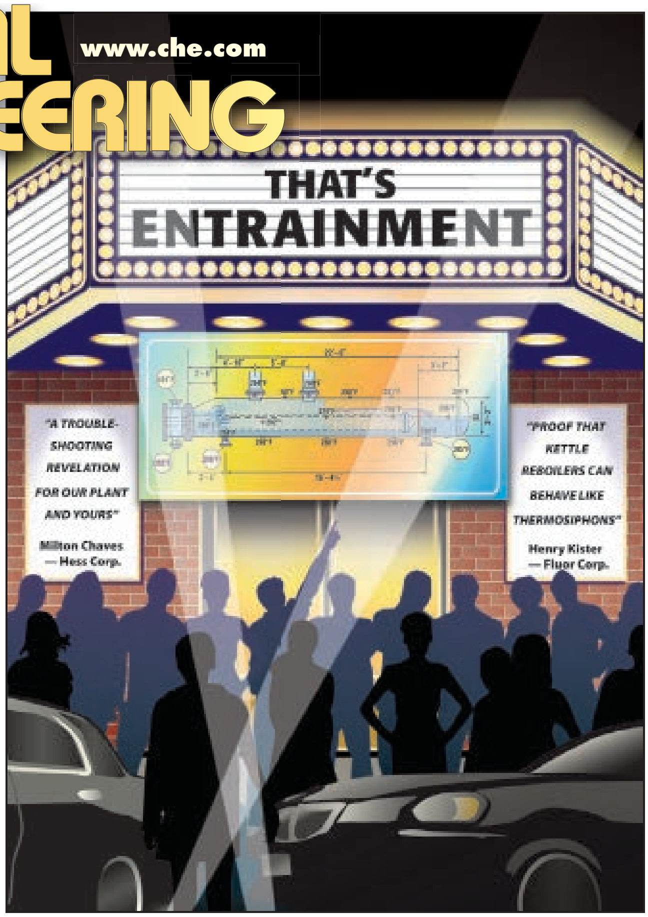
Circle 4 on p. 54 or go to adlinks.che.com/29247-04

CHEMICAL ENGINEERING



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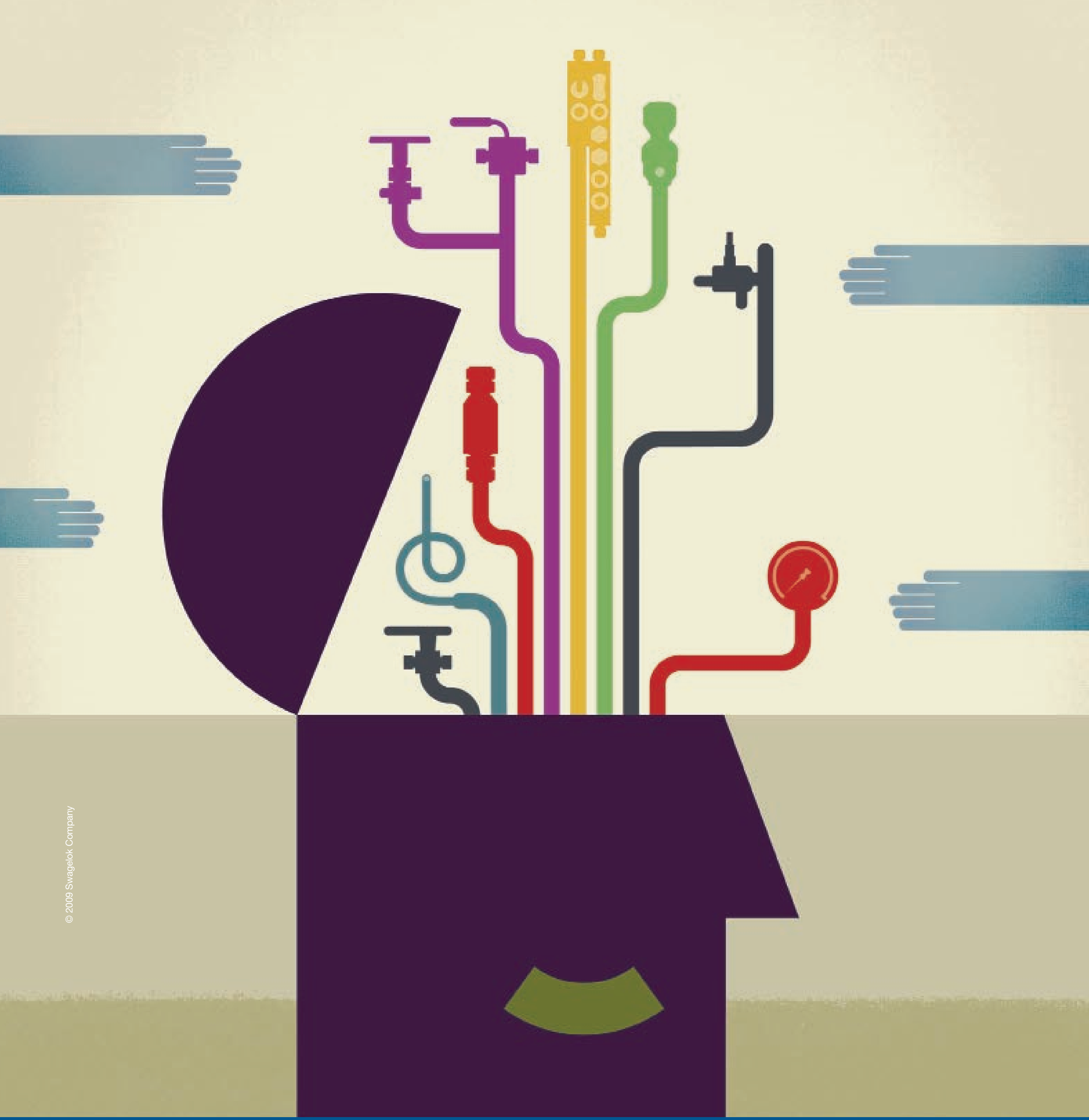
Cover: David Whitcher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CHEMICAL ENGINEERING

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Editor's Page

Status of worldwide R&D

Late last month, in an event at the White House, the U.S. National Science Board (NSB) released its *Science and Engineering Indicators 2010* report. Produced every two years by NSB — the governing body for the National Science Foundation (NSF; Arlington, Va.; www.nsf.gov) and NSF's div. of Science Resources Statistics — the *Science and Engineering Indicators* Series is an authoritative source of U.S. and international data on science, engineering and technology. The NSF likens the publication to a report card on U.S. science, engineering and technology, comparing U.S. performance with other nations. For the broader, global context of *CE*'s audience, the report reveals a number of interesting facts about the present status and future outlook of research and development (R&D), and therefore, the innovation platform on which our profession rides.

In general, R&D expenditures indicate the priority that a nation or region gives to advancing science and technology relative to other goals. The report estimates that worldwide R&D expenditures in 2007 (the most recent year for which data is available) totaled an estimated \$1,107 billion. Even though many countries conduct R&D, for now the lion's share continues to be concentrated in a few high-income countries or regions. The U.S. alone accounts for about 33% of the current global R&D total. The next four performers are Japan (13%), China (9%), Germany (6%) and France (4%). NSB's report puts that in perspective by noting that the top two countries account for around 47% of the global R&D total, while the top five countries represent about 66%. When the report factors in the next five countries — South Korea, the U.K., the Russian Federation, Canada and Italy — the total increases to just below 80%, meaning that four-fifths of the world's R&D is concentrated in only ten countries.

There are a number of trends, however, that predict an inevitable upset in the status quo. Consider, for instance, that growth of R&D expenditures in the U.S. and the EU averaged 5–6% annually over the period 1996–2007. At the same time, comparable R&D growth rates of the Asia-8 (China, India, Japan, Malaysia, Singapore, South Korea, Taiwan and Thailand) economies often exceeded 10%, and in China's case approached 20%. Meanwhile, both India and Brazil are in the report's top-15 R&D performers and are acknowledged for essentially doubling their R&D expenditures over the past decade or so. Also noteworthy is that research publications with authors in Asia are relatively more heavily concentrated in engineering (China at 16%, Japan at 11%, and the Asia-8 at 19%) than those with authors in the U.S. (7%) or the European Union (8%), where focus instead leans toward medical research.

Another basis for the report's geographical comparisons is R&D intensity, typically measured as the ratio of a country's national R&D expenditures to GDP for a given year. This approach does not require currency conversion to a standard international benchmark and provides a way to adjust for differences in the sizes of national economies. In 2007, Israel had the highest R&D intensity (4.7%), followed by Sweden (3.6%), Finland (3.5%), South Korea (3.5%), Japan (3.4%), Switzerland (2.9%) and Iceland (2.8%). In comparison, R&D intensity was lower in the U.S. (2.7%), the EU (1.8%) and China (1.5%).

In an April 2009 speech and on several occasions since then, U.S. President Barack Obama set a R&D intensity goal of 3%. For the U.S. or any large economy today, however, an increase in R&D intensity would almost certainly fall on the back of stimulus packages. Industry's prolific cost-cutting programs have only recently begun to subside, and widescale impacts on R&D are flat at best. ■

Rebekkah Marshall

Letters

Comparing petrochemical plant aging

The massive buildup of new petrochemical capacity in the Middle East and Asia has been well documented, and its effect on future supply-demand much discussed. But a look at the average ages of plants in different regions in the years that follow this capacity buildup, prompts new conclusions on just how profound the effects of this new capacity will be.

Ed Gartner, Director of SRI Consulting's World Petrochemicals research program, has examined the aging of ethylene plants through 2015. Gartner's methodology is to compare the current- and future-average ages of plants in different regions, using 1974 as the base, or "zero" year. The regions themselves are defined by the OECD. They comprise China-India; ME-AF, which stands for Middle East and Africa, but does not include Turkey; Europe, which includes Western Europe plus Turkey, Poland, the Czech Republic, Hungary and the Slovak Republic; and Pacific, which includes Japan, Korea, Australia and New Zealand

By 2015, analysis shows that the average life of ethylene plants in China-India and ME-AF will be around 10 years, while the average of plants in North America and Europe will be around 30 years. There are several conclusions to be drawn and extrapolations to be made from Gartner's study:

- First and foremost, plants in the Middle East and China-India will have an efficiency advantage compared with plants in the rest of the world, just because of their age, scale and relatively modern technology
- Meanwhile, plants in North America, Europe and the Pacific will be candidates for closure or replacement, unless their efficiency and competitiveness can be improved and their lifespan expanded
- Shuttering capacity in North America and Europe is becoming increasingly expensive, mainly because of the requirement to remediate the sites on closure. This may lead to the lifetime of older plants being extended beyond normal expectations and/or their product slates being reformulated
- Substantial investment would be needed to rebuild older capacity, and apart from national governments and oil majors, it is not apparent who would have the wherewithal to rebuild North American, European and Pacific capacity

All of these observations point to a more rapid shift of the petrochemicals industry to the axis between the Middle East and China in the years to come. In the North American, European and Pacific regions, meanwhile, the most likely outcome will be a drive towards added-value products that can serve the domestic markets.

John Pearson, President
Access Intelligence, Chemical Business Media div.

Postscripts, corrections

December, Building a Better Dryer: On p. 28, the Website for Drytech should be drytecheng.com not drytechinc.com. ■

Calendar

NORTH AMERICA

Pittcon 2010. Pittsburgh Conference on Analytical Chemistry & Applied Spectroscopy (Pittsburgh, Pa.). Phone: 412-825-3220; Web: pittcon.org
Orlando, Fla. **Feb. 28–March 5**

Biopharmaceutical Development & Production Week ("Five Conferences In One"). IBC Life Sciences (Westborough, Mass.). Phone: 800-858-4881; Web: ibclifesciences.com/courses
Carlsbad, Calif. **March 1–5**

Global Plastics Engineering Conference 2010. Society of Plastics Engineers (Lindale, Ga.). Phone: 706-238-9101; Web: sperecycling.org
Orlando, Fla. **March 8–10**

23rd Conference of the Organic Reaction Catalysis Society. Organic Reactions Catalysis Soc. (Devens, Mass.). Phone: 805-313-5237; Web: orcs.org
Monterey, Calif. **March 14–18**

Corrosion 2010. NACE International (Houston). Phone: 281-228-6213; Web: nace.org
San Antonio, Tex. **March 14–18**

DCAT Week 2010. Drug, Chemical & Associated Technologies Assn. (Robbinsville, N.J.). Phone: 609-448-1000; Web: dcat.org
New York, N.Y. **March 15–18**

The 2010 National Symposium on Market Transformation. American Council for an Energy-Efficient Economy (Washington, D.C.). Phone: 202-507-4000; Web: aceee.org/conf/mt10/index.htm
Washington, D.C. **March 16–18**

Secrets of Batch Process Scaleup. Scientific Update Conferences (Mayfield, U.K.). Phone:+44 1435 873062; Web: scientificupdate.co.uk
Atlanta, Ga. **March 17–19**

Spring 2010 National Meeting & Expo. American Chemical Soc. (Washington, D.C.). Phone: 800-251-8629 (domestic); Phone: 508-743-0192 (international); Web: acs.org
San Francisco, Calif. **March 21–25**

NPRA Annual Meeting. National Petrochemical & Refiners Assn. (Washington, D.C.). Phone: 202-457-0480; Web: npra.org
Phoenix, Ariz. **March 21–23**

Odors and Air Pollutants 2010. Air & Waste Management Assn. (Pittsburgh, Pa.) and the Water Environment Federation (Alexandria, Va.). Phone: 412-904-6020; Web: wef.org/oap/
Charlotte, N.C. **March 21–24**

(Continues on p. 8)

Calendar

2010 Spring Meeting & 6th Global Congress on Process Safety. American Inst. of Chemical Engineers (New York, N.Y.). Phone: 646-495-1360; Web: aiche.org
San Antonio, Tex. **March 21–25**

37th Annual NOBCChE Conference. National Organization for the Professional Advancement of Black Chemists and Chemical Engineers (Washington, D.C.). Phone: 866-544-9677; Web: nobcche.org
Atlanta, Ga. **March 29–April 2**

Molding 2010: Emerging Technologies for Business Success in Changing Global Market. Executive Conference Management (Plymouth, Mich.). Phone: 734-737-0507; Web: executive-conference.com
San Antonio, Tex. **April 12–14**

SynGas 2010. SynGas Assn (Baton Rouge, La.). Phone: 225-922-5000; Web: syngasassociation.com
Tulsa, Okla. **April 19–21**

EUROPE

Second Annual Conference on Ethics and Human Values in Engineering. World Federation of Engineering Organizations (Paris). Phone: +34-93-401-1714; Web: icehve.com
Barcelona, Spain **March 2–4**

Understanding Polymorphism and Crystallization Issues in the Pharmaceutical Industry. Scientific Update Conferences (Mayfield, U.K.). Phone: +44 1435 873062; Web: scientificupdate.co.uk
Nice, France **March 22–24**

Analytica 22nd International Trade Fair. Messe München GmbH/Analytica (Munich, Germany). Phone: +49-89-949-11488; Web: analytica.de
Munich, Germany **March 23–26**

Secrets of Batch Process Scale-Up. Scientific Update Conferences (East Sussex, U.K.). Phone:+44 (0) 1435 873062; Web: scientificupdate.co.uk
Barcelona, Spain **April 13–15**

6th EE and RES Congress and Exhibition. Via Expo (Sofia, Bulgaria). Phone: +359-32-960012; Web: viaexpo.com
Sofia, Bulgaria **April 14–16**

ASIA & ELSEWHERE

World CTL 2010 Conference. World CTL (Paris). Phone: +33-1-44-01-8713; Web: world-ctl.com
Beijing, China **April 13–16**

Middle East Plastic Pipes 2010. Applied Market Information Ltd. (Bristol, U.K.). Phone: +44 117 924 9442; Web: www2.amiplastics.com/events
Dubai, UAE **May 17–19** ■

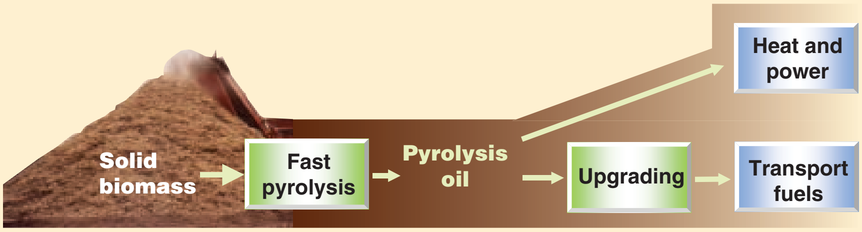
Suzanne Shelley

CHEMENTATOR

Edited by Gerald Ondrey

February 2010

Tryout set for biomass-to-gasoline process



A demonstration plant that will produce transportation fuels from cellulosic biomass will be built at Tesoro Corp.'s petroleum refinery in Kapolei, Hawaii, by Envergent Technologies (Des Plaines, Ill.; www.envergenttech.com), a joint venture of Honeywell's UOP (Des Plaines; www.uop.com) and Ensyn Technologies Inc. (Ottawa, Ont.; www.ensyn.com). Scheduled to start up in 2014, the plant will convert biomass into about 22,000 gal/yr of fuels — mostly gasoline, with a small amount of diesel fuel.

The facility will combine Ensyn's rapid thermal processing (RTP) technology with UOP's hydroprocessing knowhow to process a range of cellulosic feedstocks, including agricultural waste, pulp, paper, woody biomass, algae and dedicated energy crops, such as switchgrass and sorghum (diagram). In the RTP step, biomass is rapidly heated by hot sand to approximately 500°C, in the absence of oxygen, in a circulating transported fluidized-bed reactor. The biomass is vaporized, then rapidly quenched, yielding 65–75 wt.% pyrolysis oil, plus char and non-condensable gas, which are used for fuel. The residence time is about 2 s.

A shortcoming of bio-oils (including the pyrolysis oil) is that they contain 10–40% oxygen, versus essentially none for petroleum, as well as a high percentage of water. The UOP process deals with these issues in a two-stage hydroprocessing strategy. In the first step, H_2 combines with O_2 to form H_2O, then all the water is removed as vapor. In the second step, the partially processed oil is upgraded to gasoline and diesel fuels. The project is being funded by a $25-million grant from the U.S. Dept. of Energy (DOE, Washington, D.C.; www.energy.gov).

Lignite-fired power plant uses activated carbon to capture mercury

What is said to be the first grassroots lignite-fueled power plant to use powdered activated carbon (PAC) for mercury capture has been started up near Franklin, Tex., by Luminant (Dallas, Tex.). In its initial operation the 800-MWe supercritical plant has achieved better than 90% Hg removal, says James Brown, director of engineering for Fluor Corp. (Irving, Tex.; www.fluor.com), which built the plant. This meets the limit of 9.2 lb per trillion Btu for Hg determined in the permitting process. A second 800-MWe unit is scheduled to start up around mid-year.

Mercury from lignite and sub-bituminous coals is generally in the elemental form and hence more difficult to capture than the oxidized Hg from bituminous coals. Lignite and sub-bituminous coals lack the halogen compounds that promote oxidation, says Brown. This problem may be overcome by using more PAC or by using a brominated PAC (Br-PAC) to capture the Hg. The latter is more expensive, but the amount of brominated activated carbon required is only 20–50% as much as standard PAC.

The Luminant plant uses conventional PAC, with technology supplied by Babcock Power Environmental Inc. (Worcester, Mass.). PAC is injected into the fluegas at a rate of up to 10 lb/million acf of gas and is subsequently collected on a fabric filter, along with other particulate matter. In contrast, a 242-MWe plant that Fluor completed in 2008 at a Newmont Mining Corp. gold mine near Elko, Nev., combines Br-PAC, for fluegas treatment, with the injection of halogen ($CaCl_2$) directly onto the coal feed to enhance Hg scrubbing. The process, from Babcock & Wilcox (Barberton, Ohio), uses a lime spray-dryer absorber and fabric filter to capture both sulfur and Hg. It reduces Hg emissions to 0.02 lb/GWh.

The choice and cost-effectiveness of using PAC, Br-PAC or halogen fuel additives depends on the coal and the emissions limit, says Brown. For example, the consumption of PAC at the Newmont plant has been reduced by about 50% through the use of Br-PAC alone, and the halogen fuel additive has further reduced Br-PAC consumption by roughly another 50%. He adds that the system at the Luminant plant is capable of using Br-PAC, if the economics justified it.

Water reclamation

Last month, a new water-reclamation process for the oil-and-gas industry was launched by HBC Systems, a newly created joint venture between Hydration Technology Innovations (HTI; Scottsdate, Ariz.; www.hti-water.com) and Bear Creek Services, LLC (Albany, Ore.; www.bearcreekservices.com). The so-called Bear Creek Green Machine incorporates HTI's proprietary forward-osmosis-membrane technology, which separates water from "virtually all contaminants" as it migrates through the membrane by osmosis. The concentration difference across the membrane (needed for osmosis) is supplied by concentrated brine, which is already typically available at well sites.

The mobile unit processes wastewater at rates of more than 100 gal/min. In field tests, the Green Machine reclaimed almost 125,000 gal of reserve pit waste (using less than 20 gal of diesel fuel), which would have required 20 truckloads to transport the waste to distant disposal wells for underground injection, says HTI.

A new mineral

Minerologists from the Institute of Applied Geosciences, Karlsruhe Institute of Technology (KIT; Germany; www.kti.edu) have discovered a new mineral in Northwest Iran that may find applications in solar cells. Approved by the International Mineralogical Assoc. (IMA; Vandoeuvre-les-Nancy, France;

(*Continues on p. 12*)

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

Scaleup slated for a 'greener' cement

This summer, Celitement GmbH (Eggenstein-Leopoldshafen, Germany; www.celitement.de) will begin construction on a pilot plant to produce a new cement known as Celitement. Located at the north campus of the Karlsruhe Institute of Technology (KIT), the facility will produce up to 100 kg/d of Celitement when it starts operating in 2011, using a process first developed at KIT.

In the first step, limestone and sand (Ca-to-Si mole ratio of 0.5–2.0) and water are transformed into calcium silicate hydrates in an autoclave operating at 180–210°C and 10–20 bar. The product is dried, then mixed with a second silicate component and transformed into Celitement — a hydraulically active calcium hydrosilicate — by a reactive milling process. Additives can be used to control the hydration and the quality of the final product.

The process operates at considerably lower temperatures than that used in conventional routes to Portland clinker (up to 1,450°C), and therefore consumes about half the energy with a corresponding reduction in CO_2 emissions, says the company. The process also uses "far less" lime, and the product binding material can be handled just as ordinary Portland cement. Addition of water starts the hydration process, and the only product, calcium hydrate ($CaO\text{-}SiO_2\text{-}H_2O$), is formed. The homogeneous composition of Celitement enables easy control of hardening and product quality, with good durability and resistance due to highly connected silicate building units and low porosity.

Printed electronics made possible by this carbon-nanotube-production process

A recently commercialized method for growing single-walled carbon nanotubes (SWCNs) in large quantities enables their use in a downstream process for depositing semiconducting inks onto flexible surfaces.

Southwest NanoTechnologies Inc. (Norman, Okla.; www.swentnano.com) has developed a scalable technique (CoMoCAT process) in which carbon monoxide is decomposed into carbon and CO_2 at 700–950ºC in a fluidized bed reactor. Growth of the nanotubes depends on a specialized proprietary cobalt and molybdenum catalyst that gives rise to high selectivity.

CEO David Arthur says the process is able to generate SWCNs that are semiconducting-enriched (>90% versus 66% industry average) or metallic-enriched (>50% versus 33% industry average). The method produces nanotubes with a narrow distribution of diameters in the range of 0.8 to 1.5 nm, Arthur adds, and lengths typically 1,000 times the diameter.

In a collaboration with Chasm Technologies Inc. (Canton, Mass.; www.chasmtek.com), Southwest NanoTechnologies has incorporated its nanotubes into an ink formulation that allows them to be printed as thin films onto flexible surfaces using commercially available printing processes. A carbon nanotube paste is mixed with an evaporating ink component that dries at low temperatures (<100ºC) and leaves no residue.

Because of its electronic and optical properties, carbon nanotube ink has potential uses in various printed electronics applications, such as flexible circuits, sensors, displays, radio-frequency identification tags and others.

Making a ring of eight benzenes

Professor Shigeru Yamago and colleagues at the Institute for Chemical Research, Kyoto University (Japan; www.scl.kyoto-u.ac.jp/~yasuyuki/) have synthesized [8]cycloparaphenylene for the first time. The 11-nm-dia. molecule consists of eight benzene molecules linked together in a closed chain. The compound has a strong absorption peak at 340 nm and fluoresces yellow-green light at around 540 nm — properties that may find applications in organic light-emitting diodes (OLEDs), organic conductors and battery electrodes. Previously, other research groups have synthesized ring compounds with 9 or 12 benzenes linked together.

The compound is synthesized under mild conditions in a three-step process whereby 4,4'-bis(trimethylstannyl)biphenyl and [$PtCl_2$(cod)] (cod=1,5-cyclooctadiene) first react to form a square-shaped platinum-biphenyl intermediate. The planar complex is then separated, and heated with bromine at 95°C. A 25% yield of [8]cycloparaphenylene is achieved.

The researchers plan to apply the technique for synthesizing cylinder-shaped materials, such as carbon nanotubes (CNTs). Yamago believes their procedure will enable the control of the thickness, length and twisting degrees of CNTs.

(*Continued from p. 11*)

www.ima-mineralogy.org) and named Daliranite after its discoverer, Farahnaz Daliran, the mineral ($PbHgAs_2S_6$) is a sulfosalt, which are sulfur compounds with semiconductor metals. The soft (Mohs' hardness 1–2), red-orange mineral consists of very fine fibers (20 µm dia.), and it is an excellent semiconductor. For industrial purposes, we could grow large crystals of Daliranite, says Daliran.

A more robust sensor

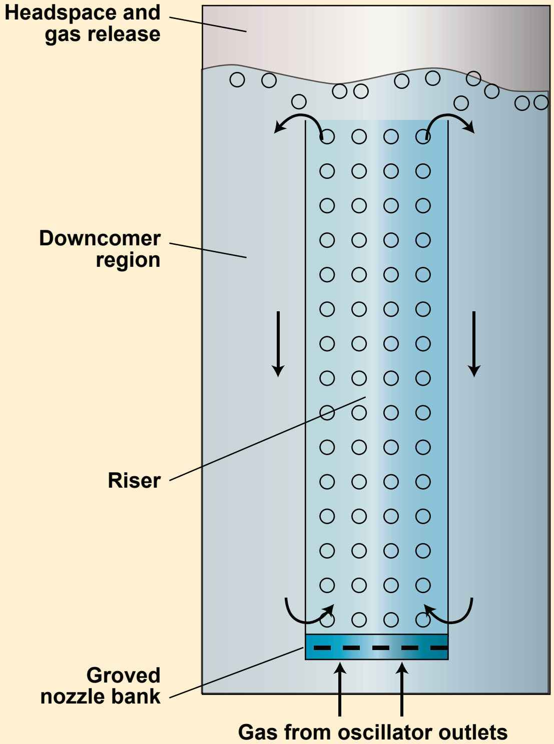
Pressure sensors used in extreme service, such as those used for monitoring drilling operations, can typically only withstand temperatures of 80–125°C. To enable operation at higher temperatures, researchers at the Fraunhofer Institute for Microelectronic Circuits and Systems (IMS; Dresden, Germany; www.ims.fraunhofer.de) have developed a pressure sensor system that can handle 250°C. Unlike conventional sensors, which are mounted on a monocrystalline-silicon wafer, IMS' device is mounted on a modified wafer of silicon-oxide, with the oxide layer providing better electrical insulation (current leakage occurs at higher temperatures). The device — composed of the pressure sensor and an EEPROM (an element for storing measurement and calibration data) — can theoretically withstand temperatures up to 350°C, but the researchers have only demonstrated operation up to 250°C thus far.

Microbubble generator enhances performance of airlift bioreactor

A patented (WO 2008/053174), fluidic-oscillator-driven device that generates microbubbles has been shown by researchers from the University of Sheffield (U.K.; www.shef.ac.uk/cpe), in collaboration with the Academy of Sciences of the Czech Republic (Prague; www.cas.cz/en), to improve the performance of air-lift loop bioreactors (ALBs). Up to 18% less energy is consumed for microbubble generation compared to conventional sparging systems, and the smaller bubbles (20 µm versus 1–3-mm dia.) lead to a 50-fold increase in mass transfer rates, says Will Zimmerman, a professor at the Dept. of Chemical and Process Engineering, University of Sheffield.

The device consists of a fluidic jet-deflection amplifier — a stack of PMMA (polymethylmethacrylate) plates with laser-milled cavities — coupled with a feedback loop. Air is supplied to the amplifier cavity and deflected to one prong or the other of a Y-shaped channel, and the oscillation (1–100 Hz) is controlled by the feedback loop — a tube of adjustable length between the two prongs. The air pulses emerging from one of the prongs then pass through a micro-machined nozzle before entering a distributor at the bottom of the ALB (diagram).

In a 250-L prototype ALB, the yield of yeast biomass grown with microbubble generation with fluidic oscillation was shown to be 15% higher compared to steady-state flow. Other applications for the bubble generator being investigated with industrial partners include aeration in wastewater treatment; flotation to remove solids from wastewater; ozone dosing in plasma microreactors, oxidation reactions; and CO_2-dosing for growing microalgae for biofuel production. In the latter example, microbubbles of CO_2 not only dissolve faster, but they also remove O_2, which is toxic to algae, and keep the suspension well mixed. Algal cultures with the fluidic-oscillator-generated bubblers had about a 30% higher yield than conventionally produced bubbles — with dosing of just one hour per day with 5 vol.% CO_2 in N_2 over a two-week trial, says Zimmerman.



Vitrification makes a product from rice husk waste

In Malaysia, about 2-million metric tons (m.t.) of rice husk are produced each year, and the rice husk is either burned or disposed of as waste. Now this waste may find application as a non-leachable building material thanks to a vitrification process developed by researchers from the University Putra Malaysia (Serdang; www.eng.upm.edu.my).

Several methods have been applied in various countries to achieve the vitrification of solid waste. It has been shown that formation of glass-ceramic upon melting and quenching can be achieved with the addition of bottom ash or glass wastes into fly ash. However, Malaysian rice-husk ash already contains 80–95% silica, so vitrification can be achieved without any additives. Research-team member Wan Azlina Ab Karim Ghani says the group selected crystabollite as the target crystalline phase of the silicate formed because of its excellent thermal and mechanical properties.

In laboratory trials, rice husk is first converted to ash by combustion at 500°C for 2 h. This ash is then placed in a refractory alumina crucible and heated to 500°C for 1 h in a Carbolite furnace. The temperature is then ramped at a rate of 10°C/min up to 1,400°C, which converts the ash into a molten glassy ceramic. The melted sample is then poured into a preheated brass cylindrical mold and immediately transferred into an electrical muffle furnace for annealing at 500°C for 1 h. The sample is then cooled to room temperature and cut into pieces using a diamond disk.

The glass-ceramic thus prepared had good mechanical properties, including a hardness of 23 MPa and compressive strength of nearly 20 MPa. Its low density and high porosity make it suitable for use as an insulator where its high porosity leads to low thermal conductivity.

Zeolite membrane

Researchers from Osaka Prefecture University (Japan; www.nanosq.21c.osakafu-u.ac.jp), Stockholm University (Sweden; www.su.se/english) and the Korea Advanced Institute of Science and Technology (KAIST; Daejeon; www.kaist.edu), have synthesized sheets of ZSM-5 (MFI-type) zeolites that are only 2 nm thick, which corresponds to the b-axis dimension of a single MFI unit cell. The sheet structure is said to improve the surface-to-volume ratio compared to conventional zeolite catalysts: the large number of acid sites on the external surface of the zeolite sheets have been demonstrated to impart a higher catalytic activity for the cracking of large organic molecules. The reduced crystal thickness also facilitates diffusion, thereby dramatically suppressing catalyst deactivation through coke deposition during methanol-to-gasoline conversion, says Osaka's Yasuhiro Sakamoto. The scientists believe the synthesis approach — which involves crystallization in bifunctional surfactants — could be applied to make other zeolites with improved catalytic performance.

Seal selection for handling and storage of biofuels

Results of 12-mo immersion tests in biodiesel and bioethanol of a range of elastomer polymers typically used in fuel-handling equipment show that the seals are prone to significant swelling, which leads to failure in valves and other equipment, according to Precision Polymer Engineering Ltd., (PPE; Blackburn, U.K.; www.prepol.com). The swelling is caused by increased acidity of the biodiesel due to oxidation. Moreover, the presence of water contamination in the biodiesel was found to accelerate the rate of elastomer swelling.

The research shows that companies handling biofuels need to be aware of the increased acidity risk of biofuels on equipment seals, and either maintain their seals more regularly to check for signs of swelling, or switch to alternative sealing materials, such as peroxide-cured fluoroelastomers, says John Kerwin, head of materials technology at PPE. The 12-mo tests have shown that: conventional NBR elastomers can be used within their normal operating parameters for both conventional gasoline and gasoline-ethanol blends, but they suffer significant swelling with biodiesel; bisphenol-cured FKM elestomers that are prone to a reversal of the rubber curing process should be replaced with peroxide-cured FKM for biofuel applications; and the rate of swelling varies, depending on the immersion conditions. For example, aged fatty acid methyl ester is more aggressive than fresh fatty acid methyl ester, says PPE.

Hydrogen from a can

A newly marketed portable reactor system for generating hydrogen is capable of generating 1,000 L of the gas in 20 min. The volume is sufficient to fill a 5-ft-dia. weather balloon, which is the first market targeted by the system's manufacturer AlumiFuel Power Inc. (Philadelphia, Pa.; www.alumifuelpowerinc.com). The company began mass production of the PBIS-1000 (portable balloon inflation system) last month and expects to deliver the first units to customers in early 2010.

The system consists of a cylindrical reaction vessel, into which are placed two 32-oz cans of aluminum powder. A hand-pump injects water into the vessel, where the aluminum powder and a mix of proprietary additives react with the water to generate H_2. The generator requires no external power and can be transported more easily than high-pressure "K-cylinders."

While the system was designed for balloon inflation in remote locations, such as that demanded by military and meteorological uses, it may be adapted for other applications requiring portable hydrogen, such as fuel cells. No greenhouse gases are emitted in the H_2 production and the products of the chemical reaction are non-toxic, says the manufacturer.

Oxygen separation membranes made in China

Researchers from the Center for Membrane Technology, Beijing University of Technology (China; www.bjut.edu.cn) have developed a new spiral-wound membrane module for use in oxygen-enriched combustion. A pilot-scale system with five membrane modules has been built and tested in a 4-ton, oil-fired boiler. According to the Center's director, professor Shulan Ji, the fuel required to generate one 1 GJ of heat decreased from 28 kg to about 26.3 kg when using O_2-enriched air, suggesting energy savings of at least 5.7%.

The membranes — a composite of polydimethylsiloxane (PDMS) and polysulfone (PS) — are made using a dip-coating method. First, PS support membranes are pretreated by sequential immersion into 25 wt.%, 50 wt.% and 75 wt.% ethanol-water mixtures and pure ethanol. Then the composite PDMS membranes are formed by dip-coating PS support membranes into the PDMS casting solution — a mixture of PDMS, the crosslinking agent TEOS (tetraethoxysilane), and the catalyst dibutyltin at a precise weight ratio in cyclohexane. It is noted that casting solution concentration, coating time and coating speed greatly influence the membrane performance.

Membrane modules (4-in. dia, 1-m long) are then made from at least one pair of spaced membrane sheets interposed between spaced porous material sheets. All of the sheets are in turn spirally wound around an axially positioned hollow mandrel. The university plans to commercialize the technology. ■

Level control

Dresser Masoneilan (Houston; www.dressermasoneilan.com) has launched what is said to be the first level instrument that integrates level-transmitter, controller and switch functions into a single device. The 12400 Series combines global level control and low- and high-level switch functions into a single unit, virtually eliminating the need for additional level switches and controllers. The device features smart filtering, HART communication-protocol compatibility and an optional 4–20-mA analog-output signal.

Firefighting suits

Teijin Techno Products Ltd. (Osaka; www.teijin.co.jp), the New Energy and Industrial Technology Development Org. (NEDO; Kawasaki) and Hosokawa Micron Corp. (Osaka; www.hosokawamicron.co.jp) have developed a new fabric that incorporates nanostructure fiber for use in advanced firefighting suits that are 40% more effective in preventing burns and 15% lighter than conventional heat-barrier linings. The nanostructure is made by kneading nanoparticles of carbon into Technora fiber — Teijin's *para*-aramid fiber. Teijin and Hosokawa Micron aim to establish technology for mass producing the fabric for commercial use. Meanwhile, they are working toward the development of other fabrics with enhanced properties, such as electric conductivity, electromagnetic shielding and heat resistance, by kneading different nanoparticles (titania and silica, for instance) into the aramid fiber.

Biomass gasification

Rentech, Inc. (Los Angeles, Calif.; www.rentechinc.com) and ClearFuels Technology Inc. (www.clearfuels.com) have been awarded a conditional $22.6-million DOE grant for their project to construct a biomass gasifier at Rentech's Energy Technology Center in Denver. The gasifier will process 20 ton/d of wood waste and sugar-cane bagasse into synthesis gas, which will be further processed into liquid fuels. ❑

SUPERCRITICAL CO_2: A GREEN SOLVENT

Carbon dioxide, in its supercritical state, is being used to replace conventional organic solvents in chemical processes

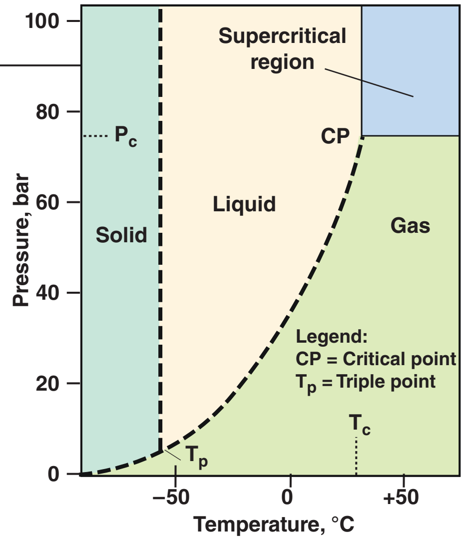


FIGURE 1. The phase diagram for carbon dioxide shows its supercritical region

Many reactions, extractions, separations and other operations in the chemical process industries (CPI) involve the use of organic solvents. In addition to handling and disposal issues, organic solvents can pose a number of environmental concerns, such as atmospheric and land toxicity. In many cases, conventional organic solvents are regulated as volatile organic compounds (VOCs). In addition, certain organic solvents are under restriction due to their ozone-layer-depletion potential.

Supercritical carbon dioxide is an attractive alternative in place of traditional organic solvents. CO_2 is not considered a VOC. Although CO_2 is a greenhouse gas, if it is withdrawn from the environment, used in a process, and then returned to the environment, it does not contribute to the greenhouse effect. There have been an increasing number of commercialized and potential applications for supercritical fluids. This article summarizes the fundamentals of supercritical CO_2 properties and processing, and presents a number of current and potential applications.

Supercritical fluids

Above its critical values, a compound's liquid-vapor phase boundary no longer exists and its fluid properties can be tuned by adjusting the pressure or temperature. Although supercritical fluid has liquid-like density, it exhibits gas-like diffusivity, surface tension and viscosity. Its gas-like viscosity results in high mass transfer. Its low surface tension and viscosity lead to greater penetration into porous solids. Because of its liquid-like density, a supercritical fluid's solvent strength is comparable to that of a liquid.

The critical temperatures and pressures of materials vary quite significantly (Table 1). Generally, substances that are very polar at room temperature will have high critical temperatures since a large amount of energy is needed to overcome the polar attractive energy.

TABLE 1. CRITICAL CONDITIONS FOR VARIOUS MATERIALS

	Critical temperature (°C)	Critical pressure (bar)
Ammonia	132.5	112.8
Benzene	289.0	48.9
Carbon dioxide	32.1	73.8
Cyclohexane	280.3	40.7
Ethane	32.2	48.8
Ethylene	9.3	50.4
Isopropanol	235.2	47.6
Propane	96.7	42.5
Propylene	91.9	46.2
Toluene	318.6	41.1
Water	374.2	220.5

At critical conditions, the molecular attraction in a supercritical fluid is counterbalanced by the kinetic energy. In this region, the fluid density and density-dependent properties are very sensitive to pressure and temperature changes. The solvent power of a supercritical fluid is approximately proportional to its density. Thus, solvent power can be modified by varying the temperature and pressure. Because their properties are a strong function of temperature and pressure, supercritical fluids are considered tunable solvents. In contrast, conventional liquid solvents require relatively large pressure changes to affect the density.

Supercritical CO_2 properties

Unlike many organic solvents, supercritical CO_2 is non-flammable. It is inert, non-toxic, has a relatively low cost and has moderate critical constants. Its solvation strength can be fine-tuned by adjusting the density of the fluid. CO_2 leaves a lower amount of residue in products compared to conventional solvents, and it is available in relatively pure form and in large quantities.

CO_2's critical temperature (T_c; 32.1°C) is near ambient, making it an attractive solvent for temperature-sensitive materials. CO_2's critical pressure is 73.8 bar (P_c; 1,070 psi), as shown in its phase diagram (Figure 1).

CO_2 as a solvent. Supercritical CO_2 is a good solvent for many nonpolar, and a few polar, low-molecular-weight compounds. It is not a very good solvent for high-molecular-weight compounds and the majority of polar compounds. Uneconomically high process pressure may be required to solvate polar, inorganic or high-molecular-weight material in CO_2. To increase the solubility of such compounds in supercritical CO_2, small amounts of

For more-detailed information, including all references see: "Supercritical CO_2: A Green Solvent," PEP Report No. 269, SRI Consulting, Menlo Park, Calif. (August 2009) Author: Susan Bell of SRI Consulting; Email: sbell@sriconsulting.com; Phone: (281) 203-6286.

polar or non-polar co-solvents may be added. Highly CO_2-soluble surfactants and CO_2-phillic ligands have also been developed to improve the solubility of compounds in CO_2.

Extractions using CO_2

Currently, the widest application of supercritical CO_2 is in extraction. Total CO_2 consumption in supercritical extraction processes is estimated to have been approximately 15,000 to 25,000 ton/yr in 1994 and between 30,000 and 35,000 tons in 2002. Worldwide, over 100 facilities are estimated to use dense CO_2 for extraction and purification. Large-scale commercial plants using supercritical CO_2 extraction are found in the food industries (Table 2).

Conventional processes for extracting various components from food products have limitations regarding the solvent toxicity, flammability and wastefulness. This area is where early commercial applications of supercritical CO_2 were focused. The relatively low critical temperature and low reactivity of CO_2 allow extraction without altering or damaging the product. Decaffeination of coffee was one of the first processes commercialized using supercritical CO_2. Prior to the use of supercritical CO_2, several different solvents including methylene chloride, ethyl acetate, methyl acetate, ethylmethylketone and trichloroethane have been used for decaffeination. Extraction of hops during the beer brewing process is another area where CO_2 is used.

The extraction process. Extraction of food and natural products with supercritical CO_2 consists of two steps: first, the extraction of supercritical CO_2 soluble components from the feed; and, second, the separation of the components from supercritical CO_2. The separation of supercritical CO_2 from the extract can be done by either modifying the thermodynamic conditions or by using an external agent. By modifying the thermodynamic conditions via changing the pressure or temperature, the solvent power of CO_2 is changed. If an external agent is used, separation is carried out by adsorption or absorption. If separation occurs with an external agent, no significant pressure change occurs. Therefore, the operating cost that is associated with pressure requirement is lower. But, an additional step is required, the recovery of the extract from the external agent. In addition, higher losses of the extract can occur during the recovery step.

The feed material is typically ground solid material, which is fed to the extractor. Most commercial operations for supercritical fluid extraction are batch or semi-batch operation especially when the feed material is solid. For liquid feed material, the extraction occurs in a countercurrent column filled with random or structured packing material. However, for highly viscous liquid feed, the viscous liquid and supercritical fluid may be mixed and sprayed through a nozzle into the extractor vessel.

Recent extraction applications. There has been a great deal of interest in supercritical CO_2 extraction beyond caffeine extraction, particularly in the preparation of high value products, such as flavors and fragrances, food supplements and nutraceuticals.

Specialty oils, for example, are high in value and typically low in volume. They have high concentrations of bioactive lipid components that are valued because of various possible health benefits. Herbal extracts from a wide range of botanical raw materials are used as ingredients to the food-and-flavor, nutraceuticals, pharmaceuticals and the cosmetics industries. Supercritical CO_2 extraction can also be used to purify materials that are used for the production of medical devices.

These high-value-product applications typically involve small volumes. Flexible, medium-capacity plants for supercritical CO_2 extraction offer toll processing for these smaller volume products. The most important driving force for using supercritical CO_2 in this application area is that it is a generally recognized as safe (GRAS) solvent that leaves no traces in the product. GRAS is the U.S. Food and Drug Admin. (FDA) designation that a chemical or substance added to food is considered safe by experts, and, therefore, is exempt from the usual Federal Food, Drug, and Cosmetic Act (FFDCA) food additive requirements.

Multi-product plants. The high capital cost of building and operating a production plant utilizing supercritical extraction promotes expanding the use of the plant to a multi-product platform. Selective extraction of multiple products can be accomplished by modifying the solvent power of the supercritical fluid. The solvent power is modified by varying the extraction pressure or by adding a co-solvent.

Another method to extract multiple products is by sequential depressurization, in which all products are extracted simultaneously. The separation step is performed sequentially through a series of separator vessels. This process is referred to as fractional separation.

A wide variety of applications

Supercritical CO_2's use in extraction processes has grown fairly quickly. In fact, extraction of food and natural products using supercritical or liquid CO_2 can be considered a relatively mature CO_2 technology. A wide range of other applications for supercritical CO_2 has been investigated, including chemical reactions, polymer production and processing, semiconductor processing, powder production, environmental and soil remediation and dry cleaning. Commercialization for these applications has, however, proceeded at a slower pace than for extraction. Several of these applications are highlighted here.

Chemical reactions. Supercritical CO_2 has been tested in a variety of industrially important reactions, such as alkylations, hydroformylations, and hydrogenation, as an alternative reaction medium. The incentives to use supercritical CO_2 as reaction medium can include (a) replacement of the conventional organic solvent with a "green" solvent, (b) improved chemistry such as reactivity and selectivity, (c) new chemistry, and (d) improved separation and recovery of products and catalysts. Relatively high rates of molecular diffusion and heat transfer are possible with a homogenous, supercritical-CO_2 reaction-medium.

Limitations to the use of supercritical CO_2 as a reaction medium include (a) poor solubility of polar and high-molecular-weight species, (b) no observed improvement in reaction chemistry in some cases, and (c) higher capital investment cost due to higher operating pressures. For reactions not limited by reactant-gas concentrations or other mass-transfer limitations, there is no improvement in reactivity observed when using a homogeneous, supercritical CO_2 medium.

Polymer production and processing. Applications of supercritical CO_2 in polymers include polymerization, polymer composite production, polymer blending, particle production, and microcellular foaming. Several applications, particularly those involving low pressures, have been successfully commercialized.

At moderate pressure, very few polymers, except for certain amorphous fluoropolymers and silicones, show any significant solubility in CO_2. Very high pressure is typically needed to dissolve polymers in supercritical CO_2. Its solvent power is weaker than that of *n*-alkanes. However, high degrees of swelling of the polymer by CO_2 can occur at significantly lower pressure. Although many polymers have very low solubility in CO_2, the solubility of CO_2 in polymers is typically high. This has led to the use of CO_2 as a plasticizer.

One example of this application area is a process to produce fluoropolymers using supercritical CO_2 as the reaction medium that was developed by scientists at the University of North Carolina (Chapel Hill). DuPont has an exclusive license for this process until 2015. A $40-million pilot plant was built in 2000 to produce fluoropolymers using this process technology.

TABLE 2. COMMERCIAL-SCALE SUPERCRITICAL-CO_2 EXTRACTION PLANTS AND PROCESSES

Process	Location	Manufacturer
Coffee decaffeination	Houston, Tex., U.S.	Maximus Coffee Group LP (formerly General Foods)
	Bremen, Germany	Kaffe HAG AG
	Bremen, Germany	Hermsen
	Poszillo, Italy	SKW-Trostberg AG
Tea decaffeination	Munchmuenster, Germany	SKW-Trostberg AG
Fatty acids from spent barley	Dusseldorf, Germany	Marbery, GmbH
Vitamin E oil, phytosterol, fatty acid methyl ester, ginger oil	Wuhan, Hubei, China	Wuhan Kaidi Fine Chemical Industrial Co.
Nicotine extraction	Hopewell, Va., U.S.	Philip Morris
Natural insecticide/pesticide (Pyrethrum extract)	High Wycombe, U.K.	Agropharm
Hops extraction	Wolnzach, Germany	Hopfenextraktion, HVG
	Yakina, Washington, U.S.	Hops Extraction Corp. of America
	Melbourne, Australia	Carlton & United Beverages Ltd.
	West Midlands, U.K.	Botanix
Spices/flavors/aromas/natural products/colors	Munchmuenster, Germany	SKW-Trostberg AG
	Rehlingen, Germany	Flavex Gmbh
	Edmonton, Canada	Norac Technologies
	Tsukaba, Japan	Ogawa Flavours and Fragrances
	Milwaukee, Wisc., U.S.	Sensient Technologies
	Japan	Kirin Food-Tech Co.

The pilot plant is capable of producing 1,100 metric tons per year (m.t./yr) of fluoropolymers. Several grades of melt-processable fluoropolymers produced from this process became commercially available in 2002. However, no further progress to develop the process beyond the pilot plant phase to a large-scale industrial process has occurred.

Semiconductor processing. Currently, chip manufacturing involves many wet-chemical processes that use hydroxyl amines, mineral acids, elemental gases, organic solvents and large amounts of high purity water during chip fabrication. One potential application is the use of supercritical CO_2 in wafer processing. The low viscosity and surface tension of supercritical CO_2 allow for efficient cleaning of small feature sizes, which is of great importance with the continued miniaturization of integrated circuits. However, the main obstacle to the use of supercritical CO_2 in semiconductor cleaning is the high cost.

Powder production. One promising application for supercritical CO_2 is the production of micro- and nanoscale particles. The pharmaceutical industry currently uses supercritical CO_2 mainly to control the powder particle size of products during synthesis. In the 1990s, a U.K.-based company, Bradford Particle Design (now Nektar), developed the Solution Enhanced Dispersion by Supercritical Fluids (SEDS) system to control powder formation from a diverse range of chemicals, including inorganic and organic substances, polymers, peptides and proteins. The use of supercritical CO_2 for micronization of pharmaceutical compounds has several potential advantages over conventional techniques such as spray drying, jet milling and grinding. These advantages include minimum product contamination, reduced waste streams, suitability for the processing of thermally, shock or chemically sensitive compounds and the possibility of producing particles with narrow size distribution in a single-step operation. ■

Edited by Dorothy Lozowski

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Honeywell

BEYOND PLANT DESIGN

Simulation software finds use in plant optimization, energy reduction and operator training projects

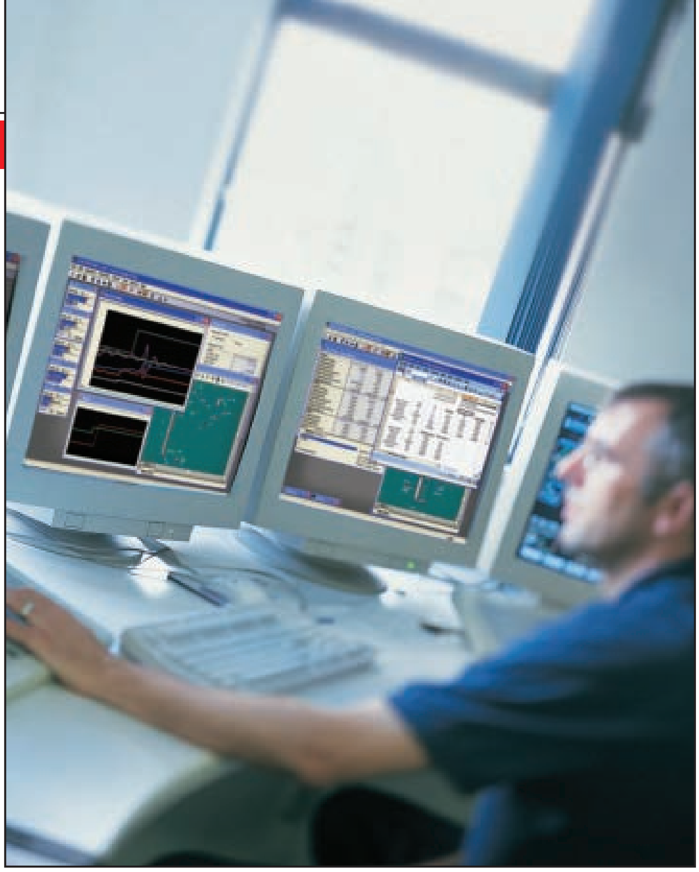


FIGURE 1. Process simulation software is quickly becoming an important, multi-use tool for chemical processors, with application in energy reduction, plant optimization and operator training projects

As chemical production shifts to growth regions such as China and India, and moves closer to areas like the Middle East, where there are less expensive sources of feedstocks, North American and European chemical processors are under global pressure to run their plants more efficiently. Throw in the trials and tribulations associated with a poor economy, and it creates an environment where management in both established and new facilities is *über*-focused on running a very tight ship. As a result, process simulation software is quickly becoming an important, multi-use tool for the chemical process industries.

In essence, process simulation is mathematical modeling and has always been a part of the engineering workflow, says Laurie Wang, senior product manager of the UniSim Design Suite with Honeywell (Morristown, N.J.). Engineers used to do it on paper and with a slide rule, but during the last few decades, the tremendous value and potential that process simulators provide have been embraced by many and have led to a transformation in technology that was unimaginable less than a generation ago, Wang notes.

And, as the technology has drastically improved, a consolidation in the marketplace has led to decreasing software costs, making simulation more available and accessible, thus allowing processors to begin using simulation software for projects beyond its original role in new plant construction.

Improvements include integration with other software tools and the ability to perform advanced calculations. For example, the ProMax simulator from Bryan Research & Engineering (Bryan, Tex.), uses the ability to integrate with Microsoft Visio, Excel and Word, as well as enhancements such as the inclusion of new data for physical solvents, proprietary data for glycol dehydration systems and thermodynamic packages, and liquid-liquid column sizing to help design and optimize processing facilities.

"Such enhancements are necessary because there are fewer specialists in engineering so process engineers are becoming more generalists," says David Tremblay, director of product management with AspenTech (Burlington, Mass.). "As a result, customers need more expertise built into their simulation software." AspenTech offers what they call "Expert in a Box." One example is the software AspenTech recently worked on with NIST (National Institute of Standards and Technology, Gaithersburg, Md.) to integrate a thermodynamics "expert" into a simulation package to provide access to data for over 15,000 pure components (in addition to the 7,000–8,000 components before the NIST agreement) and estimate the properties for an infinite number of organic components via an expert system that uses thermodynamics to fill in the gaps. "The system automatically estimates all missing properties in a consistent way so that in a matter of minutes, users can have the physical properties validated in a model," explains Tremblay.

Advanced technologies such as these, along with the ability to integrate with a variety of software tools, has led to the recent use of simulation in plant optimization projects.

"The latest trend around simulation is that there is interest and business justification in linking simulation to plant operations and engineering data to address realtime operational challenges," says Emon Zaman, vice president of Aveva Net, with Aveva (Houston).

"In existing plants, we are seeing simulation deployed to create a variety of options to help meet environmental regulations, reduce energy consumption, improve production conditions and other plant optimization projects," agrees Anne-Marie Walters, global marketing director with Bentley (Exton, Pa.). "Better links between modeling, information and operational software tied into physical plant models have allowed processors to easily and cheaply test out different options for revamp projects," says Walters.

Linking to modeling software

Though simulators provide data, but not line specifics, process flow diagrams can be generated by linking modeling software to simulators, explains Walters. The data from simulators (such as what's going on inside a pipe) can be processed with minimal engineering to achieve a list of specific line equipment and materials and the exact cost of a project.

"Because we can automate the process of moving from simulation to cost, chemical engineers can run many more simulation cases for energy reduction, optimization or environmental projects and get a cost out very quickly with a good degree of accuracy in terms of what's needed physically for a project," she says.

This, Walters notes, allows management and engineers to look at "any and all" ideas so they can find the optimal solution a lot faster and be certain about the cost and return on investment (ROI) of a project. "These days everyone is so strapped for capital that they have to have a cast iron business case for what they are going to do, and the simulation and modeling tools really help here."

To assist customers interested in this type of costing, Bentley offers Axsys.Process, which links to process simulators and automatically generates process flow diagrams and piping and instrumentation diagrams (P&IDs) and produces line lists and other two-dimensional data. PlantWise is another Bentley product applicable here. It allows engineers to model main blocks of equipment and take line lists from Axsys.Process or any P&ID and automatically lay out the plant in 3D. It also works out how long pieces of pipe need to be and other related details, and then, with the push of a button, it costs the plant or project.

Simulation meets operations

As products become more interoperable, it is becoming easier to integrate simulation products with operations systems that provide historical and asset data. "This type of tie in improves analysis of energy efficiency, productivity and product grade, and helps improve safety and reliability," says Zaman.

He says Aveva's information-management solution (Aveva Net), can assimilate technical data associated with a particular asset from other applications such as ERP (enterprise resource planning), CMMS (computerized maintenance management system) and design technologies. Many owner operators are tying that information back into simulation data to

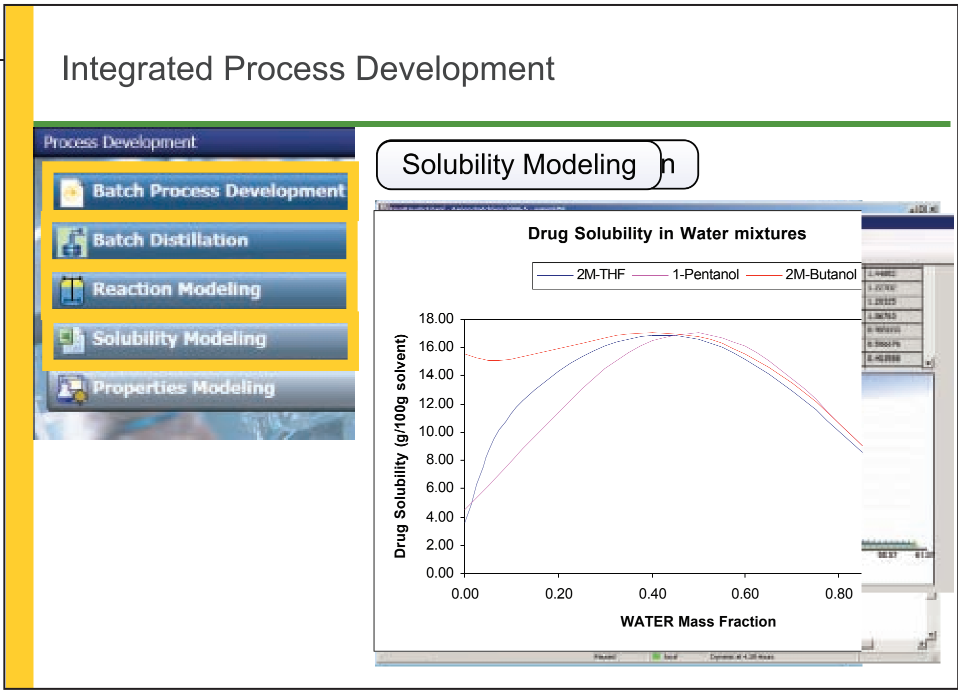


FIGURE 2. Enhancements allow simulation software to be used in a myriad of new applications. This image shows the latest enhancements to aspenOne V7-7, which now features recipe development, batch distillation, reaction modeling and solubility modeling for application in chemical processing and pharmaceutical production

allow them to perform "what if" scenarios and safety reviews to ensure that if the conditions change, the asset can handle it. In a similar vein, it can also be used to track energy use, plant productivity and product quality to find areas that need improvement and run different scenarios to see if making changes will assist with optimization without creating safety risks.

"People now realize that you can't just look at operations and simulations separately from the physical asset. They need to go hand in hand when it comes to safety and optimization," he says.

Products such as Aveva Net are available to connect these different silos of information in a common platform, allowing interoperability of information so it doesn't need to be replicated. "The person looking for information has only one place to look," notes Zaman.

AspenTech has enabled, through recently developed technologies, the ability to make a connection between plant information systems and its own simulation software so it's easier to update models frequently, making it possible to do realtime "what if" studies to help improve operations.

"Processors have begun to leverage the knowledge that's embodied in simulation software to advise operations staff on how to run things better, how to select better feedstocks, how to optimally respond to disruptions," says Sanjeev Mullick, director of product marketing with AspenTech. However, he says, this requires a tuned model, which is a model that represents the plant's current capabilities and constraints as the plant is running right now, making AspenTech's ability to import this type of data into models key to optimization.

From there, processors can use the combined information to improve day-to-day operations. For example, when it comes to energy efficiency, processors can save as much as 2%/yr on energy costs by running simulations continuously at each shift, allowing operators to tweak their utility operations by shutting down a boiler when the plant's energy demand is lower or to change from one fuel to another.

Another method of savings via optimization would apply if there's an existing energy supply contract where the price per kilowatt varies depending upon the time of day. "Using simulations in this case would allow operators to make timely decisions regarding those contracts and what equipment is used based on the time of day," explains Mullick. "And with this sort of power, the decision making is driven down to the operators, so it's no longer someone in a senior engineering role at a later date looking at where action should have been taken on a unit," he says. "Operators can now use the power of models to make realtime decisions that can have a larger impact on costs and margins."

David Hill, manager of technical support with Chemstations (Houston), agrees that using simulators in this way can provide a substantial savings, noting that many of his company's customers have identified energy savings in the five-figure-a-year range by modeling their processes and utility usage.

Taking control with simulation

Another creative use for the newest generation of simulation software is tying it into the plant control system, which sends information to a model of the plant in the simulator, permitting calculation of values that are expensive or difficult to measure.

"If you link a process simulator to your control system, the control system itself can see what is a predicted calculation from engineering thermodynamic models and decide what is a realistic expectation for the behavior of a process right now," explains Hill. "That can tell you how profitable you are at any given moment."

For example, a Chemstations' customer linked the company's ChemCAD model of a plant that was making chlorine dioxide to its control system. "The control system uses the simulation software to predict purity coming out of the plant and to predict an optimized feedrate of steam and water. It also allows operators using the control display panels for guidance, to determine when they should change the feedrates and automatically shows them how much their group is costing the company per hour per ton," says Hill. "They can calculate profitability instantly based on sensor data taken and fed through the simulator model and back into the decision making program."

Linking the simulator to the control system provides benefits because the simulator becomes a software sensor, giving a predicted value for something that was previously difficult or expensive to measure, says Hill. Running the simulator in this vein, but into the future based on current data, can also permit the simulator to observe a glitch that might become an alarm situation before an operator might spot it.

"The simulator model will recognize a dangerous situation before operator's intuition, which will lead to faster reactions and spending less time off spec," notes Hill.

Simulated operator training

Operator training simulators are becoming widely popular, as well, says Robin Brooks, managing director with Curvaceous Software Ltd. (Gerrards Cross, U.K.). "Using dynamic simulations gives process operators the opportunity to practice procedures, such as responding to an equipment failure or a unit startup that they would only infrequently encounter without simulation," he explains. "This ability to practice infrequently performed process procedures and explore and practice plant operations (such as reacting to a simulated equipment failure, which would otherwise be too dangerous to try in a real plant) is invaluable."

Honeywell, too, believes in the power of using simulation for operator training. The company takes the dynamic process modeling environment of its UniSim Design and adds regulatory control simulations for training purposes. Combining industrial control configuration at the operator station, allows the introduction of plant production scenarios that are simulated to allow operators to conduct plant startups and practice the use of Honeywell control systems, says Peter Henderson, senior product manager for Honeywell's UniSim Operations Suite. Operators can also practice procedures for normal and abnormal conditions.

"This means that the process simulation is behind the scenes creating all the dynamics you would normally see in the plant," explains Henderson. "It's connected to a Honeywell automation system as a way to provide operators with a dynamic station and control system, making it difficult to perceive the difference between operating the actual plant and operations during a simulation," he says. "This introduces a world of industrial scenarios that an operator can be exposed to years before he may ever see them in actual control situations, giving him time to learn to respond and deal with normal and abnormal situations."

"The beauty of using simulation for optimization and training is that you can play games — view different scenarios, run different feed constitutions, different feed tray locations, try to operate the unit differently and see that there might be a better way without taking any risks," Hill says. "It makes it so much easier and cost effective to find the optimum way to run a unit or group of units to reduce costs such as energy fuel and feedstocks and to train personnel." ■

Joy LePree

PROCESS SIMULATION SERVICE PROVIDERS

Ansys	www.ansys.com
AspenTech	www.aspentech.com
Aveva	www.aveva.com
Bryan Research & Engineering	www.bre.com
Bentley	www.bentley.com
Chemstations	www.chemstations.com
Curvaceous Software	www.curvaceous.com
Emerson Process Management	www.emersonprocess.com
Honeywell	www.honeywell.com
Intergraph	www.intergraph.com
ProSym	www.prosym.net
PSE	www.psenterprise.com
Simsci-Esscor	www.simsciesscor.com

CHEMICAL ENGINEERING
FACTS AT YOUR FINGERTIPS
Department Editor: Scott Jenkins

Positive Displacement Pumps

Pumps are essential equipment in the chemical process industries (CPI). Given the imperatives to reduce production costs and maximize energy efficiency, pump selection is crucial. Knowledge of pumping basics, along with the fluid characteristics for a particular application can help engineers make the best choice.

While the majority of pumps in use in CPI plants are kinetic energy pumps (the largest category being centrifugal pumps), positive displacement (PD) pumps are an important class of industrial equipment. The following is a collection of information on several types of PD pumps and an outline of the differences between positive displacement pumps and centrifugal pumps.

SELECTION STARTING POINT

In pump selection, first consider what the expectations of the pump will be. The following parameters must be determined before a pump can be selected:

Inlet conditions — To avoid suction problems, the pump should be located as close as possible to the liquid supply

Flowrate — The flowrate requirements for the pump should be considered

Differential pressure — Smaller pipe size and longer pipe runs reduce initial system cost, but the higher pressure differential raises energy consumption and reduces pump lifetime

Liquid characteristics — The properties of the fluid to be pumped — including material compatibility, viscosity, sensitivity to shear stress and presence of particulates or solids — are important factors

PD VERSUS CENTRIFUGAL PUMPS

PD and centrifugal pumps behave differently. As a means to move liquids, centrifugal pumps rely on kinetic energy, forcing liquid out of the pump with energy imparted to the liquid as it moves toward the outer diameter of a rotating impeller (pressure is created and flow results). PD pumps work by capturing confined amounts of liquid and transferring them from the suction to the discharge port (flow is created and pressure results).

The following plots represent examples of the performance behavior differences for centrifugal and PD pump types:

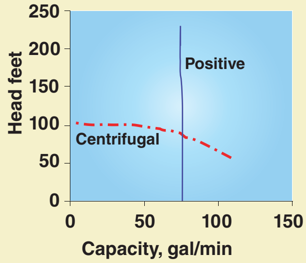
A. Flowrate versus pressure — Centrifugal pumps exhibit variable flow depending on pressure, whereas the flow in PD pumps is largely independent of pressure

B. Efficiency versus viscosity — For centrifugal pumps, efficiency decreases at greater viscosities. Positive displacement pumps are actually more efficient at higher viscosities

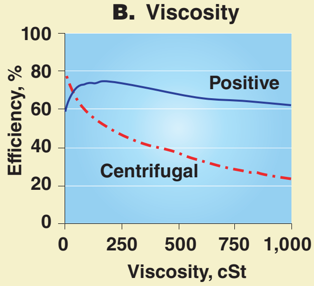
C. Flowrate versus viscosity — Centrifugal pumps lose flow as viscosity increases, while the flow of a PD pump can actually increase at higher viscosities

D. Efficiency versus pressure — Changes in pressure have minimal effect on PD pumps, but have a dramatic effect on centrifugal pumps.

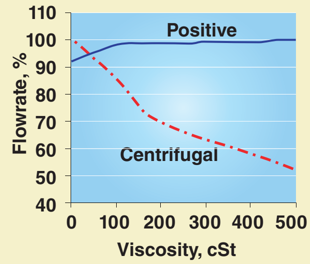
A. Performance



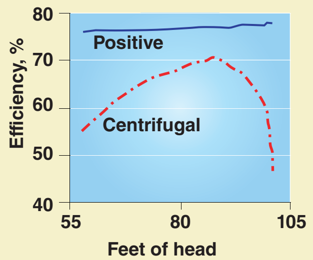
B. Viscosity



C. Flowrate



D. Head



PD PUMP OPERATING PRINCIPLES

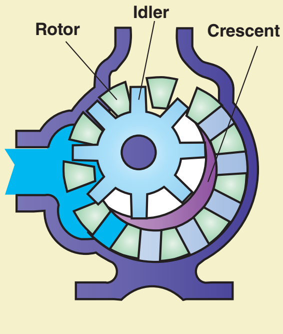
- PD pumps displace the same volume of liquid with each rotation of the shaft, so flow is proportional to pump speed
- PD pumps are self-priming
- PD-pump mechanics require close-fitting internal parts with some running clearance
- PD pumps require a pressure-relief mechanism (either relief valves or rupture discs) in case of discharge blockage

TYPES OF PD PUMPS

Internal gear pumps

Internal gear pumps have an outer gear called the rotor that is used to drive a smaller inner gear called the idler. The idler gear rotates on a stationary pin and operates inside the rotor gear. As the two gears come out of mesh, they create voids into which the liquid flows. When the gears come back into mesh, volumes are reduced and liquid is forced out of the discharge port. A "crescent" is formed between the two gears that functions as a seal between the suction and discharge by trapping the volume of liquid carried between the teeth of the rotor and idler.

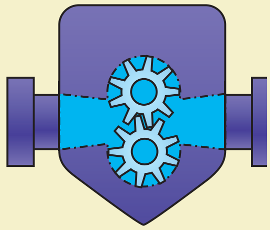
Internal gear pumps are effective with viscous liquids, but do not perform well for liquids containing solid particles.



External gear pumps

External gear pumps have a similar pumping action to internal gear pumps in that two gears come into and out of mesh to produce flow. The difference is that external gear pumps have two identical gears rotating against each other. Each gear is supported by a shaft with bearings on both sides of each gear.

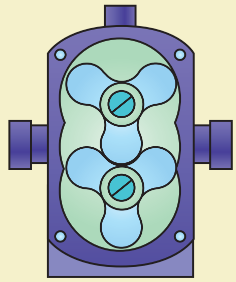
External gear pumps work well in high-pressure applications, such as hydraulics, but are not effective in applications requiring critical suction conditions.



Lobe pumps

Lobe pumps resemble external gear pumps in operation, except that the pumping elements do not make contact. Lobe contact is prevented by external timing gears.

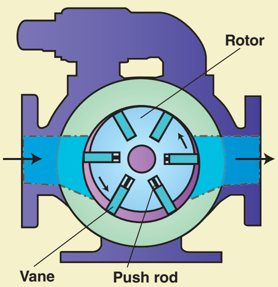
Lobe pumps perform well with liquids that contain solid materials, but do not perform well with low-viscosity liquids.



Vane Pumps

Sliding vane pumps have a rotor with radial slots, and it is positioned off-center in a housing bore. Vanes that fit closely into rotor slots slide in and out as the rotor turns. Pumping action is caused by the expanding and contracting volumes contained by the rotor, vanes and housing.

Vane pumps are effective for low-viscosity liquids, and when dry-priming is required. They are not ideal for abrasive liquids.



References

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2. Viking Pump Inc., When to use a Positive Displacement Pump, The Pump School Website, Viking Pump Inc., www.pumpschool.com, 2007.
3. Soares, C., "Process Engineering Equipment Handbook," McGraw Hill, New York, 2002.
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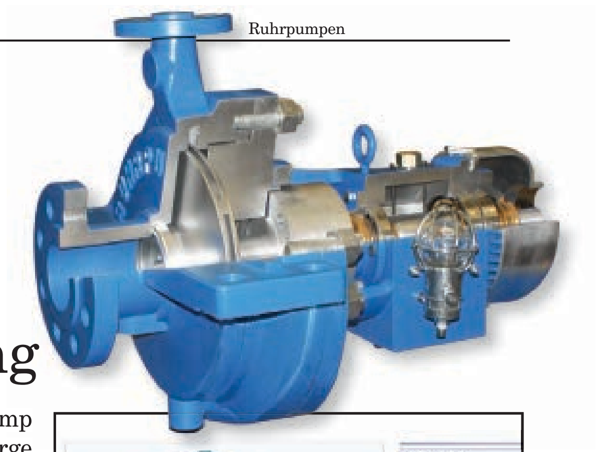
MARCH 15-18, 2010
26th INTERNATIONAL PUMP USERS SYMPOSIUM



Ruhrpumpen

Pump Symposium Focuses on Technology and Troubleshooting

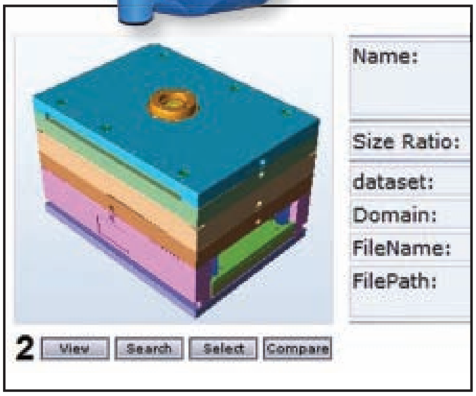
The 26th International Pump Users Symposium will be held from March 15–18, 2010 at the George R. Brown Convention Center in Houston. This international meeting will emphasize pump technology and troubleshooting. The symposium is one of two annual gatherings sponsored by the Texas A&M University Turbomachinery Laboratory, and is co-located with the Multiphase Pump User Roundtable (MPUR), which takes place March 17.

The event is led by engineers from the petrochemical, process, utility, contractor and consulting fields, along with manufacturers of rotating equipment and fluid-handling equipment. In addition to an exhibition, the symposium features lectures, tutorials, discussion groups and short courses.

Visit *Chemical Engineering* at booth 722. The following is a sampling of products appearing at the symposium:

Find design files quickly with this search software

CADseek is a search algorithm (photo) designed to help those using CAD software locate files in a heavily populated document management system. The algorithm is based on three-dimensional geometric shapes, and can find and compare instrument parts and assemblies for varying degrees of geometric similarity. It performs a search to find identical and similar parts, mating parts, assemblies, castings or forgings. CADseek can also use metadata to help refine a search. Files are grouped by similarity and displayed as part families. CADseek supports several widely used, design software products. Booth 629 — *Impac Systems Engineering, Houston, Tex.*
www.impacsystems.com



Impac Systems Engineering

This pump is available in many size combinations

The new version of the SCE Model centrifugal process pump (photo) is available with 75-volute, casing-pump sizes and with centerline discharge nozzles from 1–12 in. The pumps are also available for 50- or 60-Hz power supplies, resulting in 118 hydraulic combinations for customer applications. The improved pump includes refinements to the pump shaft and bearing bracket, and is appropriate for refineries, petrochemical plants, oil fields and pipelines, as well as offshore, marine and dock services. It meets the standards established in API 610 (Centrifugal Pumps for the Petroleum, Petrochemical and Natural Gas Industries). For low-NPSH (net positive suction head) applications, an optional inducer can be installed. Booth 123 — *Ruhrpumpen GmbH, Witten, Germany*
www.ruhrpumpen.com

These pump baseplates are constructed of polymer composite

Pump baseplates from this company are constructed of Zanite polymer composite, an epoxy-quartz aggregate that resists corrosion and dampens vibration. Booth 115 — *BaseTek LLC, Newbury, Ohio*
www.basetek.com

Surface process can lengthen MTBM/MTBF

This surface process for silicon carbide running components demonstrates the same performance as synthetic diamond coatings without the risk of delamination. Silicon carbide running components that undergo the process are said to exhibit dramatically improved mean time between maintenance (MTBM) and mean time between failure (MTBF). It is appropriate for mechanically sealed pumps, magnetic drive pumps, compressors or mixers, bearings and shafts. The treatment converts the component's surface to a covalently bound, low-friction matrix of graphite and particulate nanocrystalline diamond. Treated surfaces can run dry, in a vacuum or inert gases, and thus can provide protection from flashing or dry-running failures. Booth 824 — *Carbide Derivative Technologies Inc., Tucson, Ariz.*
www.carbidederivative.com

This company offers a range of mechanical seal components

Featured products for this company include seal rings constructed from silicon carbide, tungsten carbide, alumina ceramic and graphite. Booth 819 — *Ningbo Ocean Fine Ceramic Technology Co., Fenghua, China*
www.noc-cn.com

Use Linux OS with this pump design software

A new version of PumpLinx simulation software can be used with the Linux operating system. The software is designed to improve pump efficiency, minimize cavitation, control pressure ripple and reduce noise. PumpLinx enables the engineer to create a virtual test article and generate flow visualization and engineering output as accurate as a full-scale hardware test in less time and with less cost. The new version of the software adds rolling vane and radial piston templates to the existing pump templates. Booth 107 — *Simerics Inc., Huntsville, Ala.*
www.simerics.com ■

Scott Jenkins

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

FEBRUARY

New Products

Christ Aqua Pharma & Biotech

CEM Systems

AtlasCopco Compessors

Syrris

Exair

This blower applies rotary screw technology

A prominent design feature of ZS Series blowers (photo) is their application of rotary screw compression technology. The rotary screw concept helps the blower to operate at efficiencies 35–40% higher than traditional tri-lobe blowers at a compression ratio equal to one. ZS products are positive-displacement, rotary-screw compressors with an integrated gearbox that drives intermeshing compression rotors, reducing energy losses compared to a belt-driven machine. The intake air is compressed between the rotors and their housing. Three sizes of the blowers, from 5 to 100 hp, are available. Primary uses for the ZS blowers are for aeration of wastewater at water treatment plants, moving grain or powders off railcars, and for cooling extruded plastic in non-woven textile plants. — *AtlasCopco Compressors, Rock Hill, S.C.*

www.atlascopco.com

This laboratory reactor can handle the pressure

The Atlas Sodium Pressure System (photo) is a modular laboratory reactor capable of operating up to 250°C and 200 bar. The reactor is available with volumes of 160, 300 and 450 mL, and offers heating/cooling, overhead or magnetic stirring, pressure sensing, and monitoring and control of pressure and mass flow. Designed for high temperature and pressure applications, such as performing hydrogenation and carbonylation reactions, the system also features maximum temperature and burst-disc cutouts to ensure that the system is completely safe and compliant with PED/ASME design codes. — *Syrris Ltd., Royston, U.K.*

www.syrris.com

Enforce tighter security with this portable fingerprint reader

The S3020f Portable Fingerprint Reader (photo) can be used in conjunction with the manufacturer's AC2000 system range, and is said to offer a new level of roaming security to the industry. With a large internal database and supporting multiple card technologies, the reader enables fully integrated biometric verification as well as card validation to be carried out remotely. The reader allows random ID card and fingerprint security checks to be carried out at temporary entrances where no mains power is available, thereby preventing "card sharing." One of the reader's features is the Occupancy Mode, which allows a head count of individuals in a defined area. For example, patrolling checks can be performed on workers coming into construction sites on buses to ensure that all passengers have authorized access. — *CEM Systems, Belfast, Northern Ireland*

www.cemsys.com

Eliminate static electricity from surfaces with this air jet system

The new static-eliminating blowoff station (photo) delivers a concentrated

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

Circle 21 on p. 54 or go to adlinks.che.com/29247-21

flow of ionized air to remove dust and other contaminants from a charged surface. It is ideal for benchtop and machine mounting to clean parts and eliminate the static electricity charge that attracts dust and contaminants. The system minimizes compressed air use by inducing surrounding airflow at a ratio of 5:1. The airstream carries static-eliminating ions to the targeted surface, neutralizing the charge in less than half a second. A flexible hose that holds its position keeps the airflow aimed at a specific spot until physically bent or moved to another position. The magnetic base allows easy mounting and includes a foot pedal valve for hands-free operation. Applications include cleaning products and containers, as well as removing contaminants from parts prior to surface coating, painting, screen printing or ink jetting. — *Exair Corp., Cincinnati, Ohio*
www.exair.com

Michell Instruments

Drift-free dew-point measurement is now portable

The Optidew Transportable dew-point hygrometer (photo) combines the drift-free performance of the chilled-mirror principle with the convenience of a transportable instrument. Housed in a specially designed case, the device is both fully self-contained as well as small and lightweight. The instrument offers a wide measurement range from the equivalent of less than 0.5 up to 100% relative humidity, and measures dew points as dry as –40°C at ambient temperatures. — *Michell Instruments, Ely, Cambridgeshire, U.K.*
www.michell.co.uk

A faster way to evaporate solvent from laboratory samples

When used with this firm's DriBlock heaters, the Techne Sample Concentrator (photo, p. 24D-5) provides fast solvent or diluent evaporation with no sample loss. The height-adjustable head of the concentrator delivers a flow of inert gas that removes evaporated solvent from the surface of solutions in tubes or 96-well plates. The combination of heating from below and the flow of inert gas provides faster evaporation when compared to traditional methods of reducing the volume of solvent, which can take many hours. The concentrator features a patented gas chamber mounted on a fully adjustable stand. Inert gas is directed onto the sample surface via a set of stainless-steel needles positioned in a

Bibby Scientific

silicon matrix. Any sample format can be accommodated. — *Bibby Scientific Ltd., Stone, Staffordshire, U.K.*
www.bibby-scientific.com

A control device that cuts energy consumption for making WFI
The new WFI-Flex (WFI = water for injection) power control can help reduce energy costs in water treatment. With the WFI-Flex control for all multi-stage water systems, operation is possible in a range from 10 to 100% at maximum load. The power is increased or decreased as a function of the level in the tank; so the number of on-off switching cycles can be greatly minimized. The system is always running at optimal levels — with improved energy efficiency and a simultaneous reduction of media and heating steam. When used in a system such as the Multitron (photo, p. 24D-2), with a capacity of 15 m^3/h, a "six-figure sum per year" can be saved quickly, by dispensing with just four startup and shutdown processes per day, says the manufacturer. Also, the distillation system has been completely redesigned for WFI production, and now offers it with an increased capacity range of up to 17 m^3/h. — *Christ Aqua Pharma & Biotech, Vaihingen/Enz, Germany*
www.christaqua.com

A vibrating feeder with built-in bulk hopper inlet
This firm's line of volumetric Rectangular Feeder Machines (RFM) has been extended to include the compact, self-contained RFM Integra Series, vibrating feeders with a built-in bulk hopper inlet. This new Series has an integrated hopper and feeder design that relies on the actuation of two electrical vibrators to ensure a constant, reliable flow of castings, billets and other large parts. The design is also suited to a number of applications in the chemical process industries (CPI). Engineered for continuous flow control, the Series eliminates the need for steeply angled hopper walls associated with gravity hoppers. The Integra models offer a lower overall height and hopper walls angled at less than 30 deg for reduced material dump height. — *Cleveland Vibrator Co., Cleveland, Ohio*
www.clevelandvibrator.com


Colder Products


Kokeisl Industrial Systems

Transfer problematic solids with this robot

The Picking Robot (photo) is a new, automated guided vehicle with weighing scale to collect components directly from a silo or container that is equipped with this firm's Discharge and Dosing Device. Picking of even sluggish and bridge-prone material within a wide range and with high precision is possible. The system is modular and expandable. — *Kokeisl Industrial Systems AG, Schönenwerd, Switzerland*
www.kokeisl.com

Connect a pump to almost any container with this adapter

The new DrumQuik 3-port Universal Dispensing Adapter (photo) enables a pump to be connected to virtually any container. Suitable for use in both low-flow dosing and high-flow transfer pump applications, the adapter facilitates the connection and disconnection of multiple chemical lines in a process while minimizing chemical exposure and maintaining workplace safety. The adapter features a 3/4-in. NPT male thread that will mate with common drum bung plugs or bottle caps with a female 3/4-in. thread. Three ports enable liquid removal, venting or blanket gas and recirculation if needed. The DrumQuik is made from food-grade, virgin polypropylene material. — *Colder Products Co., St. Paul. Minn.*
www.colder.com

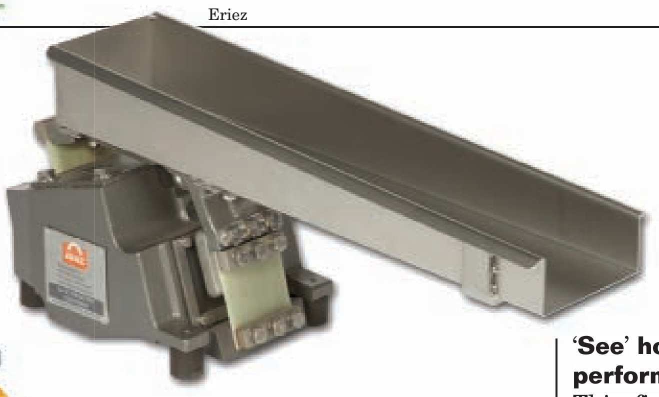
This gas seal exhibits a self-cleaning effect

Cartex GSDN bi-directional gas-lubricated seals can be used to standardize new centrifugal pumps or recondition existing pumps that have conventional stuffing-box packings or liquid-lubricated mechanical seals. The characteristic design feature of the Cartex Series is a seat and shaft sleeve that rotates along with the pump shaft, while the springs remain stationary. Internal pressurization together with centrifugal forces creates a self-cleaning effect at the sliding faces during ongoing operation. This prevents harmful contamination and increases operational reliability, especially in applications where the media contains solids. Other design features of the Cartex GSDN are high axial tolerance and the absence of dead space. The seals have silicon-carbide-face materials and a high-strength diamond-like carbon (DLC) coating ensure optimal performance in continuous operation. — *EagleBurgmann LP, Houston, Tex.*
www.eagleburgmann.com

Manage tank inventories from anywhere in the world

BinLink is a Web-based monitoring solution for bins, tanks and silos that enables remote wireless inventory management of stored material from any computer connected to the Internet. The core components of the solu-

Emerson Process Management



Eriez

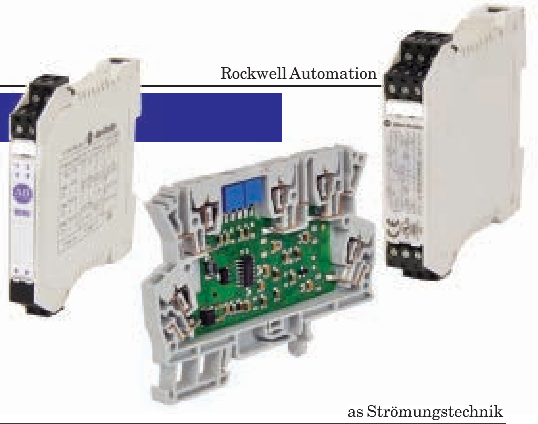
tion are the company's SmartBob2 and SmartBob-TS1 sensors mounted on the bins, a wireless or wired data-communications network, a gateway to provide connectivity to a personal computer or IP network and data collection software that can be viewed by any authorized individual via an Internet connection. — *BinMaster, Lincoln, Neb.*
www.binmaster.com

The launch of full redundancy for Smart Wireless monitoring
Available with the DeltaV S-series digital automation system, full redundancy (photo) protects the wireless network from any single point of failure by allowing primary failover to ensure that data are always delivered, even if there is a malfunction. The enhancements include redundant wireless I/O, power and communications and a redundant Smart Wireless Remote Link. The Remote Link can be mounted in class 1/Div. 1/Zone 0; it easily links the wireless field network into a DeltaV system, which makes an optimized PID available for wireless control. The new full redundancy increases the strength of Smart Wireless technology as a complement to wired and bus approaches of capital projects. — *Emerson Process Management, Baar, Switzerland*
www.emersonprocess.eu

Software for NIR administration, network and remote access
SimPlus software allows users to monitor and administer multiple DA 7200 near-infrared (NIR) analysis systems (onsite or remote installations) from one location. Users can also access data and results, update calibrations and create reports. As a result, quality control managers can immediately track production results from multiple facilities; purchasing departments can monitor ingredient quality and evaluate suppliers; production managers can access necessary analyses to optimize production; and NIR support staff can monitor calibration performance and update instruments remotely. For feed manufacturers, SimPlus offers the additional benefit of integration with formulation software packages. — *The Perten Instruments Group, Stockholm, Sweden*
www.perten.com

'See' how these X-ray machines perform without a site visit
This firm has introduced a way for users to view the performance of its X-Ray machines live online. This eliminates the need for an on-site facility visit, saving time and money. Users will "virtually" attend the material test in realtime via a password-protected Website. Participants will see their products passing through an E-Z Tec X-Ray Inspection System (photo) to determine performance for foreign object detection, mass, fill level or missing items. Multiple viewers can observe from different locations and ask questions live to company personnel. — *Eriez, Erie, Pa.*
www.eriez.com

New Products



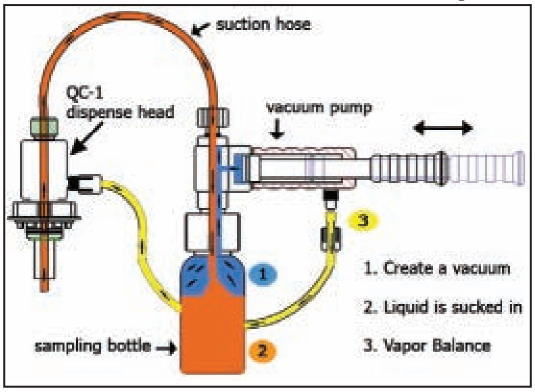
Rockwell Automation

New fail-safe modules for an I/O station

This company has improved the performance and increased the functionality of the fail-safe modules for its modular Simatic ET 200M I/O station. The new ET 200M modules (24F-DI, 8 F-DO and 10 F-DO) are now able to meet the requirements of the safety levels SIL3 (Cat. 4/PLe) in mixed operation with standard modules, without the need of a safety protector. The new modules are equipped with PROFIsafe Profil 2.0. enabling them to be used in Profinet networks. The narrow (40 mm) design of the ET 200M 10 F-DO is now suitable for a cable length of 1,000 m, offering P/P switching (current sourcing) and has a switched current of two amplifiers per channel. — *Siemens AG, Industry Automation Division, Nuremberg, Germany*

www.siemens.com/industry

as Strömungstechnik



Perform ultrapure sampling with this quick connect unit

The quick connect QC-S Liquid Chemical Sampling Unit enables rapid and safe collection of laboratory samples for the highest purity applications and most aggressive liquids. The unit (diagram) is composed of a hand-operated vacuum pump that aspirates samples via the dispensing head into a sampling bottle. Transferred chemicals only make contact with the 1/4-in. withdrawal tubing and the inside of the sampling bottle. No cross contamination can occur. Excessive vapor or minor chemical overflows can be safely returned from the pump to the drum or intermediate bulk container. — *as Strömungstechnik GmbH, Ostfildern, Germany*

www.asstroemungstechnik.de

Isolate and amplify analog signals with this conditioner

The Bulletin 931 analog signal conditioner (photo) isolates multiple signals on the same power source, which can reduce group-loop and common-mode noise. Designed specifically for process applications involving batch or continuous operations, the Bulletin 931 can be incorporated into an existing control system to convert a wide range of signals from field devices into a standard 4- to 20-mA signal. The product helps users extend the performance and functionality of legacy control systems. — *Rockwell Automation Inc., Milwaukee, Wisc.*

www.rockwellautomation.com

Software to view process variables, alarms and quality control

Visual Explorer 2.5 (CVE 2.5) is the fifth release of this firm's Geometric Process Control (GPC) software this decade. GPC technology mathematically unites, for the first time, the three key plant applications of process control, alarm management and quality control to achieve business objectives. The program allows users to view hundreds of process variables and their alarm limits in a single graph. CVE 2.5 includes new features in alarm management, process stewardship and production reporting, continuous process control, process analysis and trouble shooting, and spectral analyzer support for process analytical technology (PAT). One of the highlights of CVE 2.5 is its batch process analysis and control feature, which enables the analysis of multi-stage and multi-phase process data without the need to do any calculations or data manipulations. — *Curvaceous Software Ltd., Gerrards Cross, U.K.*

www.curvaceous.com ■

Gerald Ondrey and Scott Jenkins

WHO'S WHO


Green


Löebbert


Rabie


McElhattan


Douglas

Bently Green joins **Black & Veatch's** global water business (St. Louis, Mo.) as client accounts project director.

Mustang (Houston) promotes *Mike Dear* to CFO.

Borealis AG (Vienna) appoints *Gerd Löebbert* executive vice-president for base chemicals.

Michael Bauer becomes CFO of **GEA Group AG**'s (Bochum, Germany) newly created segment GEA Mechanical Equipment, which includes EA Tuchenhagen (flow components), GEA Niro Soavi (homogenizers) and GEA Westfalia Separator (mechanical separator).

Mike Bayda joins **Brooks Instrument** (Hatfield, Pa.) as global level product manager.

Hamid Rabie is now senior vice-president of technology at **Koch Membrane Systems** (Wilmingon, Mass.).

Declan McLaughlin is named president of Columbian TecTank, a subsidiary of **CST Industries** (Kansas City, Kan.).

Justin McElhattan is promoted to president and CEO of **Industrial Scientific** (Pittsburgh).

Dean Douglas becomes president of **Pump Solutions Group** (PSG; Grand Rapids, Mich). Formed by Dover Corp., PSG includes Wilden Pump & Engineering, Blackmer, Mouvex, Neptune Chemical Pump, Griswold Pump and Almatec. ■

Suzanne Shelley

Kettle Troubleshooting

Henry Z. Kister
Fluor Corp.
and
Milton A. Chaves
Hess Corp.

Here's proof that kettle reboilers can behave like thermosiphons and thereby bottleneck an entire plant. Understand the mechanism to blame and avoid it with these prevention and troubleshooting tips

A survey of tower failures [1] ranks kettle reboilers as the most troublesome reboiler type in the chemical process industries (CPI). Excessive pressure drop in kettle reboiler circuits is the prominent kettle malfunction, causing liquid to back up in the tower base beyond the reboiler return elevation. This high liquid level leads to premature flooding and capacity loss. In almost all the surveyed cases, the excess pressure drop is due to hydraulic restrictions in the kettle inlet or outlet piping or at the kettle entrance [2].

What is often unappreciated is that in many of the troublesome cases, entrainment plays a key role in tower base backup. Entrainment from kettle reboilers incurs a static head and more friction, which exacerbates kettle outlet-line pressure drop [3]. Furthermore, the entrained liquid drops get knocked out in the tower and return to the kettle, raising the flows and pressure drops through the kettle circuit.

Entrainment from kettle reboilers occurs when the disengagement space above the bundle is insufficient to disentrain liquid droplets. Several criteria and rules of thumb for preventing entrainment are available, the most popular of which is keeping the top tube row not higher than 60% of the shell diameter [4–6]. Other criteria include keeping a minimum height of 12 in., or 1.3–1.6 times the bundle diameter (whichever is greater) above the liquid level [7]. A more rigorous criterion for setting the disengagement space is proposed by Tammami [8].

The problem for troubleshooters is that until now, there have been limited literature reports of entrainment from kettle reboilers. Hartman and Hanson [9] reported a case with three parallel, dissimilar kettles, where an excessive liquid level set in one draw compartment induced overflows in all-three draw compartments, entraining liquid into the vapor lines, high pressure drops in the kettle circuits, and flooding in the tower.

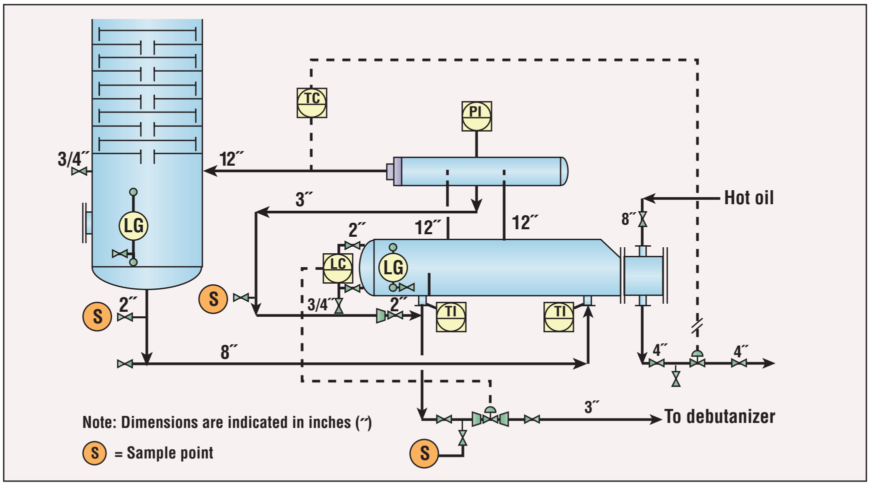


FIGURE 1. **Comprehensive field tests, conducted on the depropanizer kettle reboiler circuit in the Hess lean-oil gas plant, verified that kettles can thermosiphon**

Rubbers et al. [3] reported entrainment from a kettle reboiler in extractive distillation service, leading to excessive pressure drop and to an overflow of the chimney tray in the tower that was feeding the kettle. Rubbers' field investigation, which utilized surface temperature surveys, pressure drop measurements and hydraulic calculations, identified boiling maldistribution in the reboiler as the root cause. A theory explaining all the observations subdivided the reboiler into a stagnant region, an intense boiling region, and a kettle region. The intense boiling region was characterized by entrainment into the overhead line, low fractional vaporization, and relatively high concentration of light components.

This article shows that this intense boiling region is not unique to extractive distillation but may occur in many other applications. Further, we demonstrate that the intense boiling action can develop into a full-blown thermosiphon action. A thermosiphon reboiler is one in which substantial liquid circulation develops between the reboiler and the column due to the density difference between the liquid in the column and the two-phase material in the vapor return line.

Although one of the authors encountered cases where a kettle reboiler was hypothesized to behave like a thermosiphon reboiler, this is the first time where this behavior was actually monitored and demonstrated by comprehensive field tests. The findings demonstrate that entrainment from kettles is a major issue that needs to be considered when kettle reboilers are designed, revamped or troubleshot. Meanwhile, the methods described here illustrate how to best troubleshoot a kettle reboiler and diagnose entrainment.

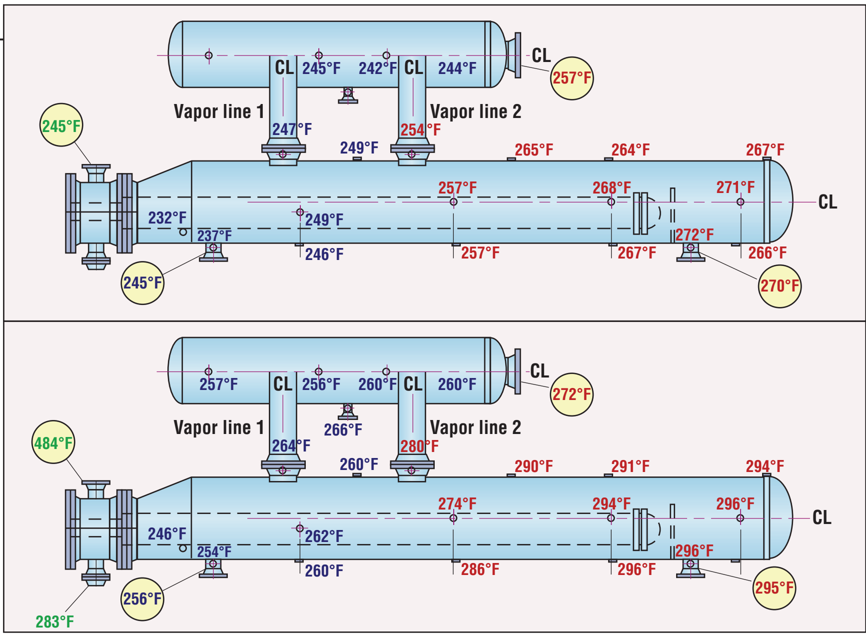


FIGURE 2. Surface temperature surveys show an inlet region, with temperatures close to the kettle liquid feed, and a much hotter outlet region. Test a (above) is at 140 gal/min feed; Test b (below) is at 195 gal/min feed

Operating history

The depropanizer in the Hess lean-oil gas plant in Tioga, N.Dak. contains 40 two-pass trays at 24-in. spacing and is equipped with a kettle reboiler heated by lean oil, which enters the reboiler at 490°F and leaves at 285°F (Figure 1). Process liquid from the depropanizer bottom enters the kettle via an 8-in. line. There are two 12-in. dia. vapor-lines leaving the reboiler. These lines go into a disengagement drum that has a 30-in. inside diameter (ID) and is 12-ft long. Vapor from the drum returns to the depropanizer via a horizontal, 12-in. dia. line. Liquid knocked out in the drum flows via a 3-in. dia. line into the kettle liquid outlet. Inside the kettle, unboiled liquid overflows a baffle into the kettle draw compartment and is withdrawn on level control. The kettle shell is 36 $^5/_8$-in. ID and contains 344 tubes that are $^3/_4$-in. outside diameter (OD) and 20-ft long, set on a 1-in. square pitch and arranged in four tube passes. This design gives a total heat transfer surface area of 1,350 ft^2. The overflow baffle is 10 $^5/_{16}$-in. below the top of the shell.

The tower and reboiler system have the nameplate capacity of 263 hot gal/min of feed. For decades, the plant operated well below its nameplate capacity and the tower experienced no bottleneck. Recently, economics favored higher plant throughput. When the depropanizer feed was raised to 205 gal/min, flooding occurred near the bottom of the tower. This flood bottleneck limited throughput of the entire gas plant.

Operating experience showed that at feedrates of less than 160 gal/min, the column operated well, and no level was seen in the tower's bottom level glass. As the feedrate was raised, a liquid level became visible. As feedrates were raised from 160 to 205 gal/min, this level was observed to first rise very slowly, then faster. Above 205 gal/min it shot right up and above the reboiler return inlet. Once it rose above the reboiler return inlet, the tower was observed to flood.

A preliminary hydraulic evaluation and tower gamma scans confirmed that the flooding initiated at the reboiler circuit and not in the tower. The force balance for the reboiler circuit showed that at the last feedrate below flooding (200 gal/min), the pressure drops in the inlet and outlet lines were too small to cause anywhere near the observed liquid stackup in the tower bottom sump. This preliminary force-balance calculation did not account for liquid entrainment from the kettle.

Field testing

Theories about the cause of the bottleneck included entrainment from the kettle, plugging of the reboiler inlet line, heavies accumulation in the kettle and more. To narrow down the possible causes, it was decided to perform a two-day test at two depropanizer feedrates: 140 gal/min, where little liquid was observed at the bottom of the tower; and 195 gal/min, about the highest feedrate at which the tower operated steadily. Fluctuations in the tower feed and operation were minimized during each test.

A complete set of tower gamma scans was performed at the higher tower feedrate of 195 gal/min. It showed that all the trays were in place, holding 3–7 in. of liquid, with center downcomers holding 6–9 in. of liquid. Little entrainment was visible in the vapor spaces, and there were no signs of flooding or even an approach to flooding in the tower. This was confirmed by the low pressure drop in the tower.

At each feedrate, the reboiler inlet line was gamma scanned at seven locations to look for possible blockage. Measured liquid densities at all points and planes did not vary. The hot specific gravity measured by the scans (0.46) was incredibly close to that calculated from the temperature and composition of the stream (0.45). This test showed that the reboiler inlet line was liquid-full and that there was no indication of any blockage in it.

Neutron backscatter measurements of the liquid level in the tower sump were in excellent agreement with the tower-base level glass. At the 140 gal/min test, the liquid level in the tower was 4 in. below the bottom tangent line (*TL*), rising to 14 in. above the *TL* in the 195 gal/min test.

The two vapor lines from the reboiler to the disengagement drum, and the horizontal vapor line from the drum to the tower, were gamma scanned along various planes. These scans established that there was a large amount of entrainment from the kettle reboiler to the disengagement drum and from the drum to the tower. This entrainment increased with the tower feedrate.

Several extensive tests followed, and are described in detail in the box that begins on p. 28. Summarized below are the key findings.

Laboratory analysis. Lab analyses found that at the 140 gal/min feedrate test, the disengagement drum liquid was only slightly heavier than the depropanizer bottoms feeding the kettle, indicating that the drum liquid came from the reboiler inlet region. The converse occurred in the

TESTING METHODS

TABLE 1. CHEMICAL ANALYSIS OF REBOILER INLET & OUTLET STREAMS, WT.%						
	140 gal/min test			195 gal/min test		
Component	DC_3* bottoms	Drum liquid	C_4+	DC_3 * bottoms	Drum liquid	C_4+
C_3	0.38	0.27	0.08	0.31	0.31	0.21
C_4	71.21	67.29	47.63	65.44	52.79	46.02
C_5	17.85	19.55	24.58	21.21	24.47	25.37
C_6	5.81	4.47	13.46	2.39	10.21	11.17
C_7	2.82	4.55	8.00	2.01	9.71	11.49
C_8	1.52	3.50	5.50	4.98	2.04	5.33
C_9+	0.41	0.38	0.76	3.64	0.48	0.39

* Depropanizer

Lab analyses

The depropanizer bottoms, the disengagement drum liquid, and the C_4+ (kettle draw liquid stream combined with disengagement drum liquid) were sampled and analyzed. The sample points are marked on Figure 1. The C_4+ composition was verified by a component balance on the downstream debutanizer.

The results are shown in Table 1. At the 140 gal/min feedrate test, the disengagement drum liquid composition was only slightly heavier than the depropanizer (DC_3) bottoms feeding the kettle, and much lighter than the C_4+ stream. This indicates that the drum liquid for this test was entrained from the reboiler inlet region, where the depropanizer bottoms stream enters the kettle. The converse occurred in the 195 gal/min feedrate test, where the disengagement drum composition was only slightly lighter than the C_4+ stream, and much heavier than that of the depropanizer bottoms stream. The reason for this behavior is discussed later (Composition and temperature behavior, p. 31).

Temperature surveys

Surface temperatures were measured using a laser-guided pyrometer, which was calibrated with measurements of the depropanizer bottoms and the kettle liquid draw temperatures. Figures 2a and 2b show the measurements for the 140 and 195 gal/min feed tests, respectively. Pyrometer measurement locations are drawn roughly to scale on Figures 2a and 2b, with the measured temperature next to each. Surface temperatures were measured at the top, bottom, and sides of the kettle, and in the liquid disengagement drum. For clarity, only the east side temperatures are shown. Those measured on the west followed the same trend. Note that the surface temperatures were measured near the wall, at a varying distance from the tube bundle. The temperatures of the streams that enter and leave the system were measured by the process thermocouples and are the encircled temperatures marked on Figure 2.

Figures 2a and 2b distinguish two regions along the length of the kettle. In the inlet region, that stretched from the channel head to Vapor line 2 (the second nozzle from the channel head), the temperatures were only slightly higher (by no more than 4–6°F) than the kettle inlet temperatures. In the second region, which stretched from Vapor line 2 to the liquid draw, the kettle temperatures began rising right after Vapor line 2, finally reaching the liquid draw temperatures.

Temperatures in the disengagement drum were much the same as the kettle liquid inlet temperatures in the 140 gal/min test, and slightly (about 4°F) higher than the kettle liquid inlet temperature in the 195 gal/min test. Temperatures in Vapor line 1 were colder than in Vapor line 2. This supports earlier comments that much of the liquid that reached the disengagement drum was entrained from the inlet region of the kettle.

There were differences between the temperature surveys for the two tests. The temperatures in the 140 gal/min test were lower than those in the 195 gal/min test, by about 11°F at the kettle inlet and by about 25°F at the kettle liquid draw. Also, the temperature difference between kettle liquid outlet and inlet rose from 25°F in the 140 gal/min test to 39°F in the 195 gal/min test. Finally, while the kettle surface temperatures measured were completely steady and repeatable in the 140 gal/min test, they varied, by 2–3°F at the cold end, and by as much as 8°F near the hot end, in the 195 gal/min test. The reason for these differences is discussed later.

Reboiler neutron backscatter scans

This technique shoots neutrons about 6 in. into a vessel. Neutrons are reflected upon collision with hydrogen nuclei. The reflection (backscatter) count provides a measure of the concentration of hydrogen nuclei near the vessel wall. The count is high for liquid hydrocarbons where hydrogen-containing molecules are close together, and low in vapors where molecules are far apart. So a high count indicates liquid, while a low count signifies vapor. These scans only measure the liquid content near the wall and not in the bulk of the vessel.

Six neutron-backscatter scans were performed in each test. Figure 3 shows the scan locations and the results for the 195 gal/min feedrate test. The results for the 140 gal/min test were similar. In each scan, neutrons were shot every 2 in. circumferentially from the kettle top to bottom. Figure 3 plots the detector count (*x*-axis) against distance along the circumference from top to bottom.

Figure 3 shows a large amount of liquid in the vapor space above the kettle overflow weir near the kettle inlet. Scanlines 1 to 3 show high liquid content 10 in. (circumferentially) above the weir, much the same as (in Scanline 1, even higher than) the liquid content below the weir. Scanline 2 in the reboiler inlet region showed significant holdup of liquid in the vapor space all the way to the top of the kettle. After vapor nozzle 2, the liquid content in the vapor spaces gradually declined along the kettle length.

Below the weir, most scanlines showed a fairly uniform liquid content. The liquid content was higher for Scanlines 5 and 6, especially lower in the exchanger, indicating less frothy liquid. The liquid content below the weir was least in the inlet region.

The liquid disengagement drum was also neutron-scanned, with three different scanlines circumferentially from the top to the bottom. The drum did not hold much of a liquid level, less than about 2 in.

Tracer injection tests

Non-volatile tracer was injected into the reboiler feedline during the

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195 gal/min feedrate test, where the drum liquid was much heavier than that of the depropanizer bottoms. The reason for this result is discussed in the section Composition and temperature behavior (box, p. 31).

Temperature surveys. Surface temperature surveys found that there was a clear split of the kettle reboiler into an inlet region, with temperatures not much warmer than the liquid feed, and an outlet region, where most of the temperatures rise occurred.

Reboiler neutron backscatter scans. Reboiler neutron backscatter scans showed heavy entrainment in the inlet-region vapor space, between the kettle liquid inlet and Vapor line 2, gradually declining as one moves from Vapor line 2 toward the liquid draw nozzle.

Tracer injection tests. Tracer injection tests provided conclusive evidence that entrainment from the kettle was large and came primarily from the reboiler inlet area. The tests determined that the rate of liquid entrainment from the kettle to the drum was 62 gal/min. This rate was independently confirmed by measuring the column base filling rate once the drum drain valve was shut, and from bubble point calculations.

Kettle force balances

Kettle circuit force balances (Table 2) were applied to determine the aeration of the kettle liquid and the entrainment rate from the reboiler and disengagement drum to the tower. Figure 5 illustrates the force balance for the 195 gal/min test. The force bal-

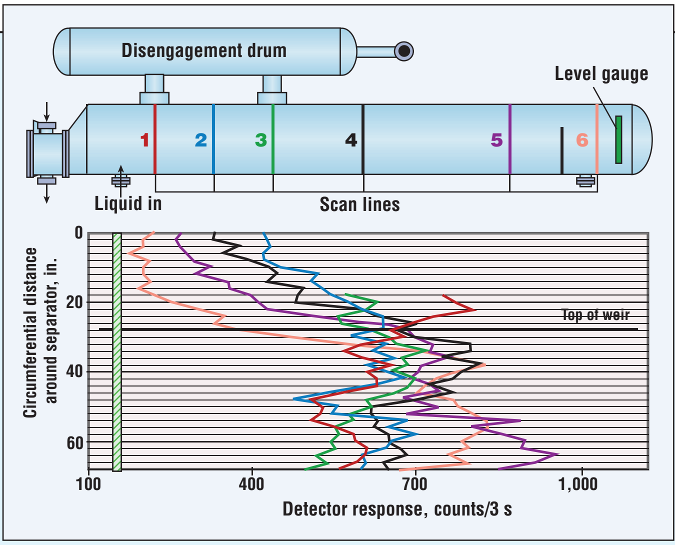

FIGURE 3. Neutron backscatter scan of the kettle reboiler at 195 gal/min feed shows heavy entrainment in the inlet region vapor space, gradually declining from Vapor line 2 toward the liquid draw nozzle

195 gal/min feedrate test. Detectors were mounted at the feedline just before reboiler entry, at the two reboiler vapor outlet lines to the disengagement drum, at the horizontal vapor outlet line from the drum to the tower, and at the reboiler liquid outlet line.

Figure 4a shows the detector responses to a pulse injection. Tracer injected at time zero reached the reboiler inlet 80 s later, giving a sharp peak (black curve), followed immediately (10 s later) by a sharp peak at Vapor line 1 (red curve). The tracer did not finish entering the reboiler when it was detected at Vapor line 1. Tracer began coming out of Vapor line 2 (blue curve) about the same time when it peaked in Vapor line 1, peaking at about 140 s. The peak was lower in counts but of a wider area, suggesting that the tracer was reasonably evenly split between Vapor lines 1 and 2. Tracer started exiting the drum Vapor line (green) at about 100 s, peaking at about 140 s.

The detection of tracer in the disengagement drum and its vapor outlet line provides conclusive evidence for entrainment. The sharp peaks, and the short duration from tracer entry to the peaks in the kettle vapor outlet lines, provide conclusive evidence that the entrainment was large and occurred primarily in the reboiler inlet region. Tracer entering the reboiler was immediately sent overhead via Vapor line 1, and after a short duration also via Vapor line 2.

The tracer reached the liquid outlet (pink curve) about 190 s after injection, and peaked at 450 s, leveling off after that.

Can the entrainment be measured?

In an endeavor to measure entrainment rate from the disengagement drum, the tracer injection test was repeated, but this time the valve in the 3 in. line draining liquid from the drum to the kettle liquid outlet line was shut just before the tracer injection. In this test, it was also desired to positively verify that all the tracer remained in the liquid. To achieve this, the detector in the drum vapor outlet line (green) was moved to the depropanizer, and mounted in the vapor space below the bottom tray. Figure 4b shows no tracer on this detector, verifying that no tracer was in the vapor phase.

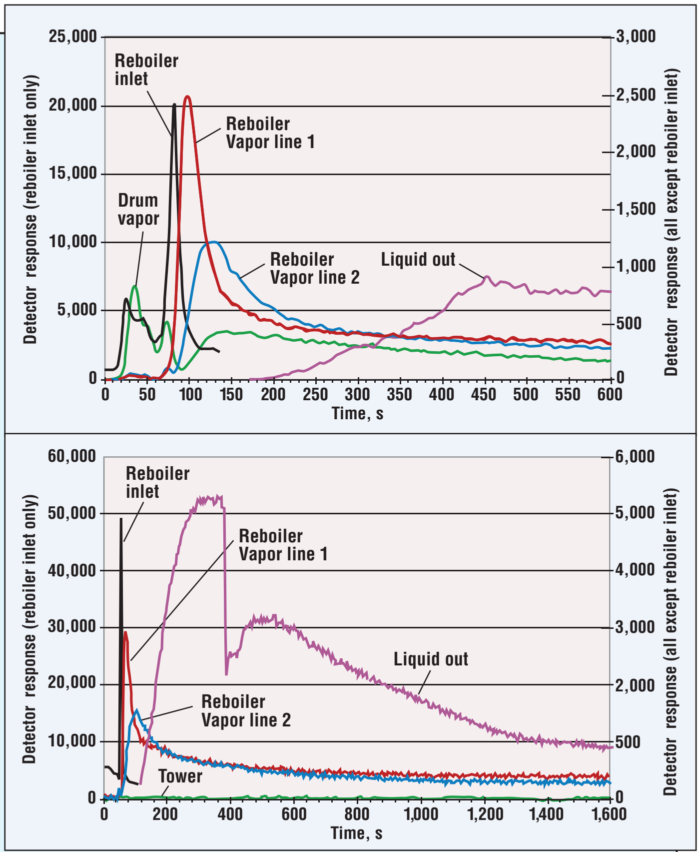

FIGURE 4. Detector response to a non-volatile tracer pulse test at 195 gal/min feed, conclusively shows heavy entrainment from the reboiler inlet area and provids means of measuring the entrainment, with (a; top) drum-drain valve open and (b; bottom) drum-drain valve closed for first 400 s

Figure 4b shows similar trends to Figure 4a in the first 200 s. Tracer peaked at the reboiler inlet 60 s after injection (black), followed immediately by a peak in Vapor line 1 (red). At about the same time, tracer was first detected in Vapor line 2 (blue), peaking 40 s later. Tracer was detected at the kettle liquid outlet after 120 s, peaking and then leveling off after about 300 s.

With the tracer in the reboiler outlet liquid steady at about 5,200 counts, the valve on the 3 in. drain-line from the drum was opened at 400 s. Immediately the detector count dropped, stabilizing at about 3,100. From that drop of counts, the flowrate of liquid from the disengagement drum can be calculated. A component balance on the tracer gives the following:

(Continues on p. 31)

ances equate the heads between the centerline (CL) of the 8-in. liquid line to the reboiler (lower reference elevation), and the centerline of the 10-in., reboiler-return nozzle (upper reference elevation).

The force on the tower side equals the liquid head measured in the depropanizer (above the lower reference) and the static head of the vapor between the liquid level and the upper reference. The force on the reboiler side is the total of three groups. The first sums the friction heads in the reboiler circuit. The second sums the liquid static head in the reboiler inlet line (from the lower reference to the reboiler entrance, the vapor static head in the vapor space between the reboiler liquid and the upper reference), and the mixed vapor-liquid static head in the vapor lines from the kettle to the drum. The third group is the reboiler liquid head (reboiler baffle height plus the liquid head over the weir), multiplied by an aeration factor. The head over the weir is calculated from the Francis weir formula [*10*]. Adding the three groups gives the total head from the reboiler side, which should equal the liquid head on the tower side.

The aeration factor of the kettle liquid is central to kettle force balance. Non-aeration is the conservative assumption often applied for design, as recommended by key literature references [*11*, *12*]. Comprehensive models [*13*, *14*] take into account the generated vapor volume and the bundle two-phase pressure drop. Recirculation of liquid inside the kettle and the existence of clear liquid zones between the

TABLE 2. REBOILER FORCE BALANCES

Case	140 gal/min		195 gal/min		210 gal/min	
% Liquid in kettle	100	86	100	86	100	86
Entrainment removed in drum, lb/h	—		13,600		14,650	
Entrainment returned to tower, lb/h			17,600	30,800	95,400	106,200
Total liquid to kettle, lb/h	91,000		146,300	159,500	234,000	244,800
Vapor from kettle, lb/h	70,100		96,100	96,100	103,500	103,500
Wt. % of total liquid vaporized	77		66	60	44	42
Force balance, column side, ft liquid						
Level in tower above reference[1]	4.67		6.25		8.75	
Vapor static head above liquid[2]	0.52		0.34		0.06	
Total head, **ft liquid**	5.19		6.59		8.81	
Force balance, reboiler side, ft liquid						
Friction in inlet liquid line	0.27		0.69	0.83	1.78	1.94
Friction in vapor lines, kettle to drum	0.04		0.11	0.12	0.2	0.22
Friction in vapor line, drum to tower	0.27		0.7	0.79	1.45	1.54
1. Total friction	0.58		1.5	1.74	3.43	3.7
Static head in inlet liquid line	2.09		2.09	2.09	2.09	2.09
Vapor static head, drum and kettle	0.24		0.24	0.24	0.24	0.24
Mixed static head in vapor lines	0.32		0.51	0.57	0.79	0.83
2. Total static heads	2.65		2.84	2.9	3.12	3.16
Kettle head over weir	0.08		0.07		0.08	
3. Aerated liquid head	2.27	1.96	2.26	1.95	2.27	1.96
Total head [1+2+3], **ft liquid**	5.5	5.19	6.59	6.59	8.81	8.81

1. Reference: Centerline (CL) of liquid line to reboiler.
2. Head from liquid level to centerline of reboiler return nozzle.

bundle and the sides of a kettle reboiler complicate such models [*13*]. The force balance for the 140 gal/min test, in which the entrainment was small (as established earlier), allowed us to derive the aeration factor based on a good measurement. This is far superior to expert opinions and mathematical models.

For the 140 gal/min test, the liquid head calculated on the tower side was 5.19 ft (Table 2). Based on non-aerated reboiler liquid, the reboiler side liquid head is about 4 in. higher. The kettle liquid aeration factor was then varied to close the force balance. This calculation (Table 2) yielded an aeration factor of 0.86 (in other words, the reboiler material below the reboiler baffle was 86% liquid, 14% vapor).

A 4-in. difference out of 5.2 ft may appear insignificant, but of this 2.09 ft is liquid head above the lower reference (equal on both sides), and another 0.6 ft is static head differences, which have little error. So the basis for the aeration factor is 4 in. out of a net head of 2.5 ft. The friction head, which is the least certain term, is only 0.58 ft. So we expect the calculated aeration factor to be a good approximation, not a mere reflection of measurement or calculation errors.

For the 195 gal/min test (Figure 5), a trial and error calculation determined the quantity of entrainment (*E*; lb/h) from the drum to the tower bottom sump that would close the force balance. This is in addition to the 13,600 lb/h entrainment knocked out by the drum and directed to the reboiler liquid outlet, which was measured as described earlier. The entrainment rate *E* that reached the bottom sump (Table 2) was at least 17,600 lb/h (assuming non-aerated kettle liquid), and most likely was closer to 30,800 lb/h (using the 0.86 aeration factor determined above).

The last force balance in Table 2 is for the 210-gal/min depropanizer feedrate. No test was performed at this rate. However, plant experience has shown that whenever the depropanizer feedrate exceeded 205 gal/min, the liquid level rose above the reboiler return nozzle and initiated column flooding. The force balance basis was on the experience that at 210 gal/min the liquid level was at the bottom of the reboiler return nozzle.

The flows through the reboiler circuit for this calculation were prorated from the 195 gal/min feed, an increase of 7.7%. The entrainment rate that closed the force balance was about 100,000 lb/h, regardless of whether or not an aeration factor of 0.86 was used.

For the 195 gal/min test, the total friction head was 1.74 ft. Prorating for a 7.7% increase in flowrates, the friction would have risen by about 16%, just less than 0.3 ft. The observed increase in liquid head was 2.2 ft. The only conceivable explanation is a massive increase in entrainment. The force balance in Table 2 estimates a huge entrainment increase from about 31,000 lb/h to 106,000 lb/h over this small 7.7% increase in tower feedrate.

In summary, the force balances revealed that the kettle liquid was about 86% liquid, 16% vapor at the 140 gal/min test. The entrainment rate from the drum to the tower at the 195 gal/min test was about 31,000 lb/h, jumping to 106,000 lb/h once the tower feedrate was raised to 210 gal/min.

Heat transfer calculations

Table 3 shows the process data measured and calculated for the kettle. Most process temperatures were measured. There was no flowmeter, nor outlet temperature measurement, on the heating medium, so the reboiler duty (and therefore the heating medium flowrate and the heat transfer coefficient) were based on the depropanizer energy balance via the tower simulation. The entrainment rate from the drum is based on the rise in tower base level when the valve was shut, which we consider to be the most reliable of the measurement methods used.

The heat transfer coefficient could not be determined for the 140 gal/min test because the outlet temperature of the heating medium was not measured. In the 195 gal/min test it was measured by the pyrometer. The heat transfer coefficient measured for the test was 96 Btu/h-ft^2-°F as compared to 95 Btu/h-ft^2-°F calculated from the HTRI software. This perfect agreement is fortuitous, but also confirms good heat transfer performance.

The kettle boiling zones

Our measurements discussed above clearly identified two boiling zones in the kettle: a colder, intense boiling region that produces significant entrainment, stretching between the reboiler

TESTING METHODS (

Continued from p. 29)

$$3{,}100\ W = 400\ X + 5{,}200\ (W - X) \quad (1)$$

Where W is the flowrate of the C_4+ stream, known from the downstream debutanizer mass balance, and X is the flowrate of disengagement drum liquid, unknown. The count of 400 was obtained from the drum vapor inlet detectors once the bottom count leveled at 3,100 counts. This is not an accurate representation for the drum liquid, but being small, the calculation is insensitive to its accuracy. Solving Equation (1) gives $X = 62$ gal/min (hot), or 44% of the C_4+ stream.

This test produced an unexpected fallout. When the valve in the drum drain line was closed, the liquid level in the depropanizer tower started shooting up. Instead of being removed by the now-closed drum drain line, the liquid was carried over into the tower base. Over the seven minutes at which the valve was closed, the level glass indicated that about 55 ft^3 of liquid accumulated in the tower base, giving an average rate of 59 gal/min. This figure was strikingly close to that inferred from the tracer component balance above.

One more way was found for calculating the drum liquid flowrate. From the composition of the C_4+ stream (Table 1) and the reboiler liquid outlet temperature, the bubble point pressure was calculated. For the 140 gal/min test, the reboiler liquid outlet temperature was 270°F (Figure 2a), giving a calculated bubble point pressure of 275 psia, close to the measured reboiler pressure of 280 psia. The close agreement suggests that the C_4+ stream for this test consisted mostly of reboiler outlet liquid, and that the liquid stream from the drum is small.

For the 195 gal/min test, the reboiler liquid outlet temperature was 295°F (Figure 2b). The bubble point pressure at this temperature and the C4+ composition (Table 1) was 324 psia, well above the measured reboiler pressure of 280 psia. The C_4+ stream was therefore much lighter than the reboiler outlet liquid. This can only happen if a large portion of the C4+ stream came from the lighter drum liquid. A component balance gives

$$W\,x_w = X\,x_x + (W - X)\,x_k \quad (2)$$

Where W is the flowrate of the C_4+ stream, known from the downstream debutanizer mass balance; x_w is the component concentration in the C_4+ stream, known from the analysis; X is the flowrate of drum liquid, unknown; x_x is the component concentration in the drum liquid, known from the analysis; and x_k is the component concentration in the kettle outlet liquid, unknown. The composition of the kettle outlet liquid x_k at the reboiler liquid outlet temperature needs to give a bubble point pressure equal to the reboiler pressure. Equation (2) and the bubble point criterion were solved simultaneously, giving $X = 79$ gal/min, in reasonable agreement with the preceding alternative methods.

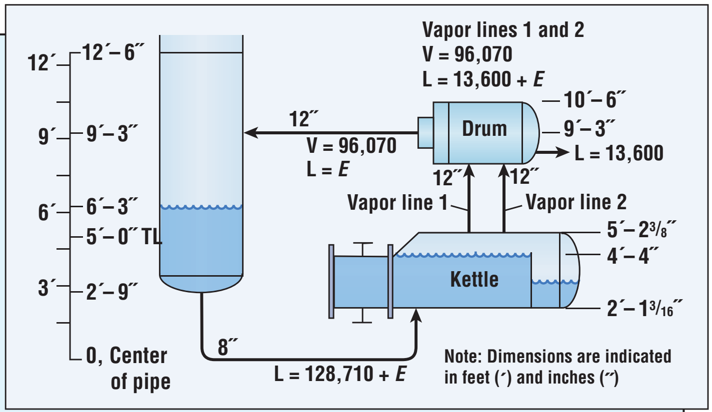

FIGURE 5. Reboiler force balances were applied to determine kettle aeration and entrainment rates (*E*; 195 gall/min test shown here; flows are in lb/h; TL = Tangent line)

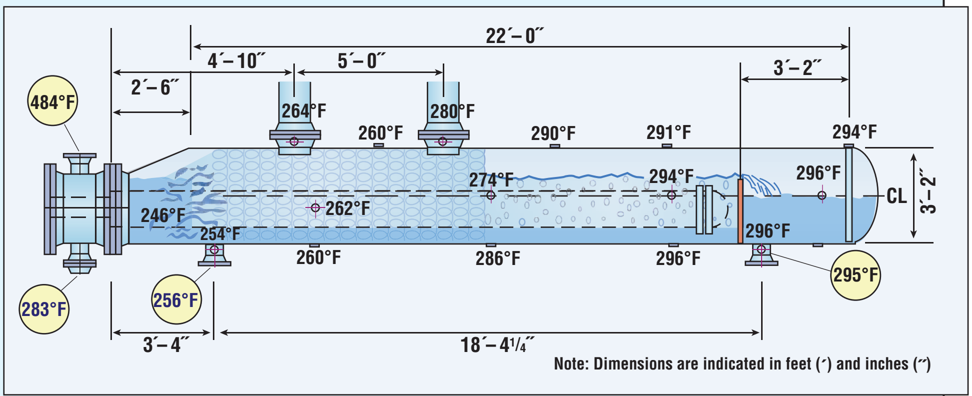

FIGURE 6. Analysis of boiling regions in the depropanizer kettle reboiler revealed that the inlet region was thermosiphoning, while the outlet region operated like a kettle

Composition and temperature behavior

Equation (2) sheds light on the movement observed in the kettle temperatures (by as much as 8°F near the outlet) in the 195 gal/min test. When the drum liquid rate X decreases in Equation (2), more lights reach the kettle outlet liquid, and its boiling point decreases. Therefore, the movement in kettle temperatures reflects variability in entrainment rate. This may also explain why the bubble point calculation gave a higher drum flowrate than the tracer and tower bottom level rise methods. In the 140 gal/min test, the entrainment rate was small, and the temperatures did not vary.

The above also explains the larger temperature difference between the kettle outlet and inlet liquid temperatures in the 195 gal/min test. Much of the light kettle liquid was entrained, making the remaining liquid much heavier, thereby increasing the temperature difference across the kettle.

The fact that 44% of the C_4+ was drum liquid explains why the drum liquid approached the C_4+ composition in the 195 gal/min test. Recycle of a large amount of entrainment, much of it not captured by the drum, accumulated heavies in the reboiler circuit. Also, more entrainment came from the region of the reboiler between Vapor line 2 and the liquid draw, as can be inferred from the larger difference between the temperatures of Vapor lines 2 and 1 in the 195 gal/min test. ❑

liquid-feed nozzle and Vapor line 2, and a low entrainment, hotter region between Vapor line 2 and the kettle liquid-draw nozzle. These are very similar to two of the three regions identified by Rubbers et al. [3] in an extractive-distillation kettle reboiler. The only region identified by Rubbers that was not clearly observed in this investigation is the stagnant liquid zone near the inlet tubesheet. The discussion below considers the application of the zones identified by Rubbers to those identified in the depropanizer reboiler (Figure 6):

Quiescent liquid region. Rubbers identified a stagnant region or dead zone in the tubesheet quadrant. With little disengagement space, not much boiling takes place, light components flash off, and the liquid becomes rich in the non-volatile components. The non-volatile liquid with little aeration incurs a high hydrostatic head, which resists movement of fresh liquid into this region. The reboiler surface temperatures measured by Rubbers in this region were high and close to the heating medium, which supports stagnation.

The average aeration of 86% liquid, determined from the reboiler force balance for the 140 gal/min test, is close to non-aerated liquid, but not quite there. So it appears that there is a relatively stagnant, or so-called quiescent-liquid zone in the depropanizer reboiler, but it was not completely stagnant.

It is important to recognize that in the extractive distillation case of Rubbers, the reboiler liquid consisted largely of a high-boiling solvent, so once the light components were flashed, the reboiler ΔT was quite small. In the depropanizer, the ΔT near the tube sheet was much larger, especially for some tube passes, so the two cases are not directly comparable.

The high L/V intense-boiling region. Rubbers observed a second region with higher-than-average upward liquid traffic to compensate for reduced flow to the stagnant region. This resulted in colder liquid temperatures but intense boiling and higher-than-average vapor generation. In the depropanizer reboiler, we too observed this region between the reboiler feed inlet and Vapor line 2.

A pressure balance across the reboiler equates the pressure difference between the bottom of the kettle and the reboiler's common vapor space, no matter which region one travels through. Along each vertical line from the reboiler bottom to the vapor space, the pressure difference is the sum of the liquid head plus the friction head. On the average, the pressure difference approaches the aerated liquid head. In the quiescent regions, the friction pressure drop is small due to the low flow. Conversely, in the intense boiling region, the intense boiling highly aerates the liquid and reduces the froth density (as evidenced from the neutron scan in Figure 3), which lowers the liquid head. This induces a high liquid flow into the region until the friction terms balance the difference between the less-aerated liquid head in the quiescent region and the highly-aerated liquid head in this region.

The vigorous boiling concentrated in this region means that the fraction of the liquid vaporized is lower, so less lights are removed from the liquid. This lights-rich liquid persists all the way to the two vapor nozzles, as evidenced from the neutron scans and the tracer tests. The lower temperatures observed in this region (Figures 2a and 2b) are the result of the high liquid flux in the tube field. The vapor nozzle closest to the tubesheet is coldest, because that is where the intense boiling starts, is more vigorous, and therefore leads to a smaller fraction being vaporized (also observed by Rubbers). At the same time, some of the liquid is projected into the vapor outlet nozzles as entrainment. The action in this region has similarities to the action in horizontal thermosiphon reboilers in that the quantity of vapor generated results in a low density froth, which promotes liquid flow to this region as opposed to the denser liquid in the less aerated zones.

The kettle boiling region. Rubbers observed a third region that actually operated as a kettle is intended to operate. In the depropanizer reboiler, we too observed this region between Vapor line 2 and the kettle liquid draw.

There is a net flow of liquid from the reboiler feed region towards the overflow baffle since this is the only manner (other than entrainment) in which the unboiled liquid can permanently exit the kettle reboiler. As the liquid moves toward the overflow baffle, it progressively contains less lights. This results in less vigorous boiling and a denser froth in this region. This was actually observed in the neutron backscatter (Figure 3). This denser froth provides more resistance to liquid from the kettle bottom and, in turn, reduces the liquid flow to the kettle boiling region.

The kettle boiling region is the one region that actually operates like it should — that is, as a kettle. There is not much entrainment here, as verified by the neutron backscatter (Figure 3), and there is a lot of disengagement space in this region, both of which promote true kettle behavior. As the flow of reboiler feed liquid through this region is relatively low, and the lights gradually disengage along the path from Vapor line 2 to the overflow baffle, the temperatures in this region gradually increase as observed by the temperature surveys (Figures 2a and 2b).

Can kettles thermosiphon?

The 195 gal/min test established conclusively that there was a large amount of entrainment from the kettle. While the entrainment knocked out in the drum was measured at 13,600 lb/h, about 30,800 lb/h entrainment continued from the drum into the tower bottom. In total, the entrainment rate for this test was 46 wt.% of the amount vaporized in the reboiler.

Proprietary software supplied by technology providers often includes an entrainment calculation for kettle reboilers. A key parameter used in the software we applied is the foam height above the overflow baffle. According to that software, to get a ratio of 0.46 by weight of the entrained vapor to amount vaporized, the foam height would need to be 3 in. below the outlet nozzles. For the 210-gal/min feed experience, the force balance (Table 2) gives a ratio of 1.03 lb entrained per lb vaporized. The entrainment calculation shows that for this ratio, the foam height needed to increase only 1–2 in. below the vapor nozzle.

Once the distance between the top of the foam and the outlet nozzle reaches 2–3 in., a kettle does not operate as a *bona-fide* kettle reboiler. It operates as a thermosiphon reboiler.

Table 2 shows the percent vaporization of the reboiler inlet liquid, as calculated from the force balances. For the 195 gal/min test, the vaporization rate was 60% by weight, declining to 42% at 210 gal/min. The latter, and even the former, vaporization rates are within the range of thermosiphon reboilers operation. So, as the entrainment escalates, so does the thermosiphoning action. The interaction between the level in the tower and the liquid circulation in the reboiler is also typical of thermosiphon reboilers, as described in Ref. *15*.

There is one large difference between the depropanizer kettle and a thermosiphon. In a thermosiphon reboiler, the liquid level in the tower is controlled, either by the draw rate (directly or indirectly), or by a constant head baffle in the bottom sump. This is not the case

TABLE 3. REBOILER PROCESS DATA

	140 gal/min test	195 gal/min test		140 gal/min test	195 gal/min test
Heat duty, MM Btu/h	7.79 [3]	10.74 [3]	Drum vapor out, °F	257 [1]	272 [1]
C_4+ flowrate, lb/h	21,060 [1]	32,640 [1]	Reboiler process liquid out, °F	270 [1]	295 [1]
Amount vaporized, lb/h	70,050 [3]	96,070 [3]	Heating medium in, °F	489 [1]	484 [1]
Reboiler feed [excluding entrainment], lb/h	91,110 [3]	128,710 [3]	Heating medium out, °F	ND	283 [2]
			Heating medium flow, lb/h	ND	81,000 [5]
Entrainment knocked out in drum, lb/h	ND	13,600 [2]	Reboiler pressure, psia	280 [1]	280 [1]
			LMTD, °F	ND	83 [4]
Entrainment from drum, lb/h	ND	30,800 [6]	Heat transfer coefficient, MM Btu/h-ft²°F	ND	96 [5]
Reboiler process in, °F	245 [1]	256 [1]			

Notes:
1. Measured by process instrumentation.
2. Measured by pyromenter or field technique.
3. Calculated from simulation.
4. Calculated from process measurements.
5. Calculated from heat duty and LMTD.
6. Calculated from reboiler force balance.
ND. Not determined.

in a kettle reboiler, where the product draw is controlled by the overflow in the kettle. This overflow has no relation to the tower base level. As the liquid head in the tower rises, the percent vaporized declines, so the liquid fraction carried over rises. As it rises, the pressure drop rises rapidly, which further increases the level, which in turn further increases the entrainment, and so on. Without a level control this response is unstable and can run away.

The force balances provide evidence that the runaway mechanism above occurs in the depropanizer kettle. The force balances show that without a sharp escalation in entrainment, the friction pressure drop should have raised the depropanizer bottom level by only 0.3 ft when going from 195 gal/min feed to 210 gal/min feed. The observed increase of that level, however, was more than 2.2 ft.

The extent to which the runaway mechanism restricts the reboiler circuit capacity can be tested by drawing product from the bottom of the tower. This test is currently under consideration. If successful, this idea is likely to permit the reboiler to operate as a thermosiphon at higher throughput. While this may not be ideal, there is no fundamental reason why a kettle reboiler should not be able to work as a thermosiphon once the runaway side effect is eliminated.

So to answer our question: yes, indeed, kettle reboilers can turn into thermosiphons.

Lessons learned

The root cause of the kettle turning into a thermosiphon is entrainment. Without mega-entrainment, there is not enough liquid to raise the liquid level in the tower base to the reboiler return nozzle elevation.

The key to preventing entrainment is to follow good design practices. The criteria recommended in the literature (and described earlier in the introductory section) should be followed. In the depropanizer reboiler, many of these criteria were violated. Specifically, the height between the overflow baffle and the top of the shell was 10 $^{5}/_{16}$ in., which is far too short. The solution recommended for the depropanizer is a larger reboiler, in which the vapor space above the overflow baffle will be large enough to prevent excessive entrainment.

The disengagement drum performed very well. It was found to remove about 60 gal/min of entrainment. Without it, the reboiler bottleneck would have occurred earlier. Adding a disengagement drum above an entraining kettle reboiler can be a good "band-aid" fix that will obtain more capacity.

Last, but not least, one good measurement is worth 1,000 expert opinions. The more good measurements, the better the troubleshooting diagnosis. Using alternative measurement techniques affords invaluable cross checks and validations. The winner is the conclusive diagnosis and a good path forward towards a solution. ■

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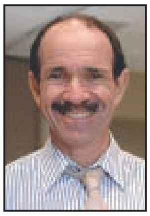
Authors



Henry Z. Kister is a senior fellow and director of fractionation technology at Fluor Corp. (Phone: 1-949-349-4679; Email: henry.kister@fluor.com). He has over 30 years experience in design, troubleshooting, revamping, field consulting, control and startup of fractionation processes and equipment. He is the author of three books, the distillation equipment chapter in Perry's Handbook, and over 80 articles, and has taught the IChemE-sponsored "Practical Distillation Technology" course more than to 350 times. A recipient of several awards, including this magazine's 2002 Personal Achievement Award, Kister obtained his B.E. and M.E. degrees from the University of NSW in Australia. He is a Fellow of IChemE and AIChE, and serves on the FRI Technical Advisory and Design Practices Committees.

Milton A. Chaves is a process engineer at Hess Corp.'s Tioga Gas Plant (Phone: 701-641-0096; Email: mchaves@hess.com). He has two years experience in design, troubleshooting and process optimization. Prior to his current position he worked for ABB and at the Hovensa refinery in St. Croix, U.S.V.I. A first-place award recipient of Texas A&M University's (TAMU) Spring Senior Plant-Design Competition, Chaves obtained his B.S.Ch.E. degree from TAMU in May 2008.

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Doing an Energy Audit

Ray Elshout
Energy Systems Engineering
Lusan Marchant
WorleyParsons

Some pointers to help you find where energy savings can be located at your plant

Today's high costs of energy make an energy audit evaluation of process facilities a must. Most plants were designed and built when energy costs were low by today's standards. This makes facilities that have not been reviewed for energy efficiency in the last few years ripe for large potential savings in energy costs, primarily from fuel and electric power. Typically, projects can be identified that have a payback of the investment cost in less than three years, and many potential projects have before-tax simple payouts of less than a year.

The energy audit is used to identify energy savings projects and prioritize the potential projects in order of their profitability. The projects have to fit the budget for future capital expenditures and be constructible, and the required shutdown tie-ins normally need to fit the turnaround schedule.

Generally, a shopping list of potential projects is first identified. These projects are then developed to the extent required to define what is in the project and how much energy can be potentially saved, estimate the economic value of the energy saved, and determine an approximate cost of the project. With this information, the projects can be prioritized.

This article provides an approach to an energy audit, several key areas to look for, and some guideline utility usage rates for a petroleum refinery. A checklist is also provided for energy savings ideas.

Starting the audit

The first step in an audit is to use historical records to determine what the past operating costs have been. A test run may be required. An overall energy balance for the unit can be determined from making a computer simulation run of the test data. This then serves as the base case for comparisons with other cases developed. Units with known high energy usage should be selected over units that are less energy dependent to get the maximum "bang for the buck". High-energy-using units usually are obvious in that they have high fuel usage, high electricity consumption, or high steam rates. From the economy of scale, larger units present more opportunity than smaller units. The 80/20 rule applies here, where 80% of the energy is used by 20% of the units.

The three most important areas of energy usage are as follows:

- Fuel gas or fuel oil
- Electric power
- Steam

Evaluation procedure

Making the evaluation methodology simple and easy to follow provides for the most expedient analysis. The first step is to ensure that proposed modifications or improvements are adequately defined and include all of the potential ramifications. For this purpose, a marked-up process flow diagram (PFD) showing circles around the areas to be modified is the best first step. Then, a simple, straight-forward description of the modification(s) is used to define what is to be done and the energy savings that are expected to result.

A marked-up piping and instrumentation diagram (P&ID) of the process is also a useful document, as are utility P&IDs. These drawings provide a means to identify and mark up potential changes.

Process data sheets, which include sufficient information to obtain budget quotations from potential vendors for the equipment, are required. These should be sent to at least two vendors (more if a major item) to get budget quotations. The key is to be sure all of the equipment is included in some type of pricing. These quotes will be the basis of determining the costs. For an initial evaluation, a factor-type cost estimate is considered accurate enough for doing ranking-type evaluations. A seasoned cost estimator can provide the factors. Both the inside battery limits and the outside battery limits (infrastructure costs) need to be included. As long as all cost estimating follows a consistent trend, evaluation among alternatives should be valid for this screening process. More detailed cost estimating methods will be ultimately used for the projects recommended from the screening process.

Areas of potential savings

From previous audits, it has been found that there are several areas that have good return on investments, including the following:

- Heat-exchanger-network pinch technology to recover more heat
- Fired-heater excess-air-control systems
- Fired-heater (including boilers and furnaces) convection-section heat recovery
- Replacing back-pressure steam drivers on non-critical rotating equipment with more efficient electric motors
- Letdown-pressure control systems for steam systems with excessive high-to-low pressure letdown
- Close-boiling separation (such as de-isobutanizers or xylene isomer separation) columns' evaluation of reflux versus adding more trays or making a less-precise separation if product purity allows
- Replacing low-efficiency motors with higher-efficiency motors on larger drivers
- Reducing pressure drop across control valves to the minimum required
- Waste heat recovery
- Repairing leaking steam traps (small items add up to large savings)

- Replacing or adding insulation to high-temperature equipment
- Process heat integration between process units in the same operating complex to better match heat-sink and heat-source temperatures as part of temperature pinch-heat-recovery improvement
- Reduce excess stripping-steam requirements to 10 lb/bbl on side streams and 20 lb/bbl on bottom streams
- Reduce lean-oil circulation rates on FCCU (fluid catalytic cracker unit) absorber-deethanizer column to minimum required

Preliminary evaluations

Once the energy savings ideas have been identified and developed to the extent the cost can be estimated and the utility savings can be determined, a simple payout analysis of capital-cost, versus operating-cost savings can be made. This very simple method is used for the screening evaluations. The important thing to remember is not to leave anything out in the equipment cost estimate and be sure that you are not double accounting any potential savings from the base case (present operation).

A shopping list of projects can be ordered in terms of increasing payback period with an arbitrary cut-off point, say three years maximum. This information can be reviewed by the capital decision makers to determine which projects are worthy of further evaluations and which projects do not make the cut.

Execution plan

It is desirable to try and group projects ultimately for making the best use of engineering, cost estimating, procurement and construction management resources. So many smaller projects may be grouped into a single larger project in terms of the execution plan. Efficient execution is the key to keeping the project costs under control.

Some of the projects may be done as maintenance work if the scope fits the resources available. Other projects will need to be farmed out to contractors. The key is to be sure all of the project scope is clearly defined and given to the contractors so they do not have to come back and re-bid items that should have been included. This is where a developed package of project description, PFD, P&ID, plot plan, piping specifications, battery limits definition, what work can only be done at turnaround time (final tie-ins), and overall timing and schedule provides the contractor with the necessary information to produce a realistic bid. Minimizing the change orders not only saves the operating company money, but prevents the contractor from stopping work until the issues are clarified.

Safety issues

The rules governing the required safety and construction practices should be known by the contractors who are allowed to bid. Previous experience on similar work is essential to developing the confidence between the contractor and the operating company. Safety today is the most important single element in doing construction work within an operating facility, even during the shutdown period.

Permits and the required construction authority issues need to be resolved early on. So the pre-construction conferences and the day-to-day communications between the contractor and the operating company's surveillance staff are essential. Keeping track of the work done versus the project plan is essential to be sure that significant slippage is not occurring, and if so, provide the backup plan.

Heat pinch evaluation

Heat exchanger network evaluation for additional heat recovery is a promising area for energy savings. Heat pinch analysis has been used over the recent past to provide the optimum heat recovery. The methodology is based on selecting a heat exchanger network configuration that best matches the heat source (hot streams) temperature with the heat sinks (cold streams) to provide the economic optimum heat recovery.

Heat pinch analysis involves shifting the heat curves of the heat sink and heat source streams to approach the most economical heat pinch. It is a trial-and-error evaluation where the heat curves are shifted closer to each other to the limit of optimum heat recovery. The heat pinch temperature is the theoretical limit at which no additional heat recovery can be achieved by transferring heat from heat sources that are at temperatures below the heat sinks.

In the heat pinch evaluation of a crude and vacuum unit, for instance, the engineer is trying to determine which of the potential heat sources shown on a pinch diagram as heat exchangers should be heat exchanged with the crude (heat sink) in the optimum order to recover maximum heat. The cumulative heat source curves are above the heat sink curves with the optimum approach temperature. This optimum approach temperature is usually about 25 to 30°F within the theoretical minimum for crude-unit heat-exchange systems.

Steam system optimization

Typical steam systems provide steam at three, and sometimes four, different pressure levels. The pressure levels are as follows:

- High pressure: 650 to 800 psig
- Medium pressure: 150 to 300 psig
- Low pressure: 40 to 50 psig

The high pressure steam is primarily used to drive rotating equipment, such as recycle compressors (with a steam turbine), that require continuous operation that cannot always be achieved with electric motors. The most efficient operation of these units is to have the compressor steam turbine discharge to a surface condenser that is run at a vacuum of 20 in. H_2O.

The medium pressure steam is primarily used as process heat. High pressure steam is let down through back pressure turbines to the medium pressure level. Additional high pressure steam may need to be let down across a control valve to maintain the medium pressure steam header pressure.

Steam from the medium pressure header is run through back-pressure steam turbines to the low pressure steam header. Low temperature heat supply, such as heater reboilers in the 250 to 350°F temperature range, is provided from the low pressure header.

Condensate from the steam system is collected in a condensate system that often includes a condensate

AUDIT CHECKLIST

The following checklist has been found useful in identifying energy savings ideas:

1. Check insulation thickness on hot lines and cold lines
2. Identify and repair leaking steam traps
3. Identify those streams that are cooled down and then reheated, and eliminate redundancy
4. Look for steam letdown from high pressure to lower pressure headers and add a power recovery turbine to use the energy if this is a common operating situation
5. Identify streams with high rundown temperatures and see if there is a matching heat sink
6. Evaluate high furnace or boiler-stack gas temperatures and determine if convection heat recovery is a potential or furnace is just being over fired
7. Identify streams that are being let down from high pressure to low pressure and determine if a letdown turbine could be used to recover the energy. Hydrocracker high-pressure separator could recovery energy in a letdown turbine and FCC regenerator off gas through a gas expander
8. Check live steam injection rates in steam strippers for excessive flow
9. Evaluate product purities to determine if fractionators are over fractionating
10. Look for heat exchangers with high LMTDs (log mean temperature differences) to determine if the exchanger is placed in the wrong location
11. Evaluate the process overall thermodynamics to see if there are potential modifications to improve energy usage
12. Evaluate large horsepower drivers with replacement by higher efficiency motors
13. Examine heat integration between units
14. Use adsorption refrigeration as a way of utilizing low temperature heat sources
15. Look for steam venting and potential use of heat
16. Evaluate shutting down the fans on air coolers in winter months
17. Evaluate recovery of all condensate to minimize BFW (boiler feedwater) feed treatment
18. Evaluate the number of trays and reflux ratio on fractionators with low relative volatility separation to determine if more trays would save energy
19. Monitor furnace excess air
20. Identify poor housekeeping practices
21. Consider use of near-infrared analysis of product quality in blending applications to minimize product reruns
22. Identify high fouling rates; take offline and clean heat exchangers as required. Chemical cleaning onstream may also work
23. Replace inefficient pumps
24. Recover fuel gas from a refinery flare header for reuse
25. Recover heat from boiler blowdown as BFW preheat
26. Reuse stripped sour water as desalter water
27. Provide variable speed drive on at least one of the cooling water circulation pumps
28. Heat source temperatures can be increased on streams such as pumparounds in crude units by increasing the pumparound flowrate to the limitation of the tower
29. Heat-sink temperature can be reduced by lowering operating pressure to improve heat pinch
30. Examine the overall refinery electric power grid to determine if induction motors can help correct the power lag factor
31. Eliminate product give-away by recovery of products at the highest economic value ❑

cooler or condenser. The condensate is then reused to generate high pressure steam. A deaerator is used to remove any soluble air before the condensate is fed to the steam makeup system. A blowdown of condensate is required to keep the dissolved solids buildup below the prescribed level for efficient heat transfer systems. Additional makeup is required, and is usually first treated in a deionizer to remove magnesium and calcium from the makeup water to minimize fouling of heat transfer equipment.

The objective is to minimize the amount of steam letdown from the various pressure headers to the next lower header as required to maintain the low header-pressure level. Recovery turbines are used to effectively recover the energy while letting the steam down to the next lower pressure level. In an efficiently designed system, various pumps or other equipment are driven by steam turbines that provide the pressure letdown. These driver services are switched back and forth between the parallel motor driven unit(s) and the steam turbine as required to balance the letdown requirements. This is a balancing act that the utility engineer performs to optimize steam usage.

Summary

It is often useful to hire a consultant to help identify energy conservation ideas by doing an energy audit. What seems to be normal practices to the operators of plants will become energy savings ideas to an independent consultant.

The first step should be just making a list of the ideas. This list can be evaluated in a number of steps to eliminate those projects that will not result in significant savings, are not economical, are not constructible, or are not in the budget limitations of the facility.

The 80/20 rule is usually applicable where 80% of the savings can come from 20% of the potential projects. Projects need to be screened which includes doing enough engineering to determine all of the elements in the project so no major surprises occur due to omission of important considerations. ■

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Authors

Ray Elshout is a process engineer for Energy Systems Engineering (Pasadena, CA 91106; Phone: 626-796-0642; Email: ritaelshout42@gmail.com). During his career, he has worked in a variety of industries and held a variety of positions. His main field is process engineering, but he has been a project manager, consultant and operations trainer. Prior experience includes a position at Jacobs Engineering where he developed the design standards for solvent extraction of vegetable oil from soybeans, winterizing, deodorizing, fat splitting, hydrogenation, glycerin evaporation and distillation. Elshoult holds both B.S.Ch.E. and M.S.Ch.E. degrees. He is a licensed professional engineer in the state of California.

Lusan Marchant is a supervising process engineer at WorleyParsons (5 Greenway Plaza Houston TX 77046; Phone: 713-407-5000; Email: lusanm@gmail.com), with over 15 years experience in process simulation and engineering in the petroleum refining industry. Specific responsibilities at WorleyParson include simulation of refinery processes, preparation of heat and material balances, sizing of equipment and supervising and monitoring of less experienced engineers. Prior experience includes positions at Wellspring Solutions, Simulation Sciences Inc., and the Ralf M. Parsons Co. Marchant holds a B.S.Ch.E. from the University of California at Los Angeles.

VARIABLE FREQUENCY DRIVES:

An Algorithm for Selecting VFDs for Centrifugal Pumps

Using this simple algorithm on a personal computer, engineers can evaluate competing scenarios to identify the most cost-effective and energy-efficient pump system design

D. K. Shukla and **D.K. Chaware**
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R. B. Swamy
Litwin PEL LLC

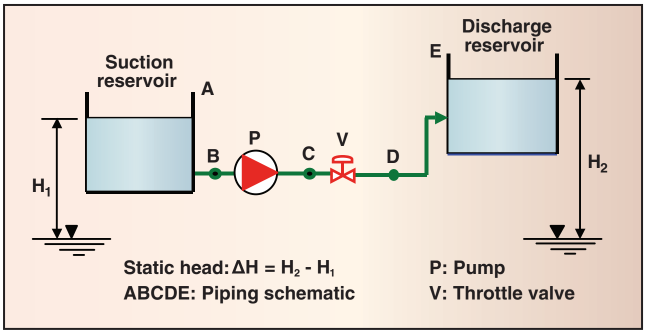

FIGURE 1. Shown here is the piping schematic for Type 1 and Type 2 pumping systems. Type 1 systems will have one operating point (see Figure 2), while Type 2 systems will have two or more than two operating points (see Figure 3) lying on the same characteristic curve

This article describes an algorithm that end users can use to develop a program on a personal computer to assess the technical and economic feasibility of installing a variable frequency drive (VFD) on centrifugal pumps. This simple algorithm serves a variety of useful functions, helping engineers to carry out the following functions:

Check the technical feasibility and evaluate whether or not it is advisable to use VFD. Such an evaluation is useful for operators considering both (a) the re-rating of pumps already in operation, and (b) the deployment of other, perhaps redundant pumps that may be warehoused at the facility.

During plant expansion and debottlenecking activities, operating parameters are commonly revised, and this calls for either the re-rating of existing equipment, the deployment of surplus equipment that may be warehoused at the facility, or the purchase of new equipment. Generally speaking, plant operators prefer to avoid new equipment purchases, which can be time consuming and costly, and instead prefer to look for opportunities to re-rate existing and available equipment at the plant. The addition of a VFD provides one option for rerating centrifugal pumps to help users gain better control and to help the units achieve greater fuel efficiency, reduced emissions and less wear and tear compared with continuous operation at some pre-determined setpoint.

Maintaining a large inventory of redundant pumps in store or using them without due consideration for energy is costly. The use of this algorithm can help plant managers to devise a proper system to use surplus or redundant pumps in the most energy-efficient way anywhere in the same plant or elsewhere.

Increase the energy efficiency of centrifugal pumps. In recent years, pressures related to rising fuel costs and environmental concerns call for the most energy-efficient operation of plant equipment. By more closely matching pump operation with actual usage requirements, the use of a VFD can help to improve the pump's performance with respect to both energy efficiency and emissions.

Critically evaluate when the use of a VFD is appropriate — and when it is not. While the use of a VFD can provide compelling advantages in some applications [*1, 2*], in other applications its use is not warranted due to technical or economic reasons, including the results of a lifecycle cost (LCC) analysis [*3*]. The simple computer-based algorithm discussed below helps the engineer to assess a large number of alternative scenarios, which is an important part of the evaluation process but calls for the systematic processing of large amounts of data. (This is explained in the case study, box, p. 42).

Support standardization efforts throughout the plant. The use of VFDs allow a particular pump or suite of pumps to be operated at different speeds, providing greater operating flexibility for the facility. This algorithm can help engineers in their efforts to evaluate whether it may be possible to standardize plant operations on a few efficient models for the entire plant, to help reduce inventory and maintenance requirements.

Methodology

To develop the algorithm, curves showing the available pump hydraulic performance characteristics — specifically, flow-versus-head, and flow-versus-efficiency curves for a set of available speed and corresponding diameter for each model — were divided into two segments. A simple quadratic equation is written for each segment. This is essential as it is nearly impossible to describe the entire performance curve using a single quadratic equation. The iterative calculation procedure, using different speeds from from minimum speed (N_{MIN}) to maximum

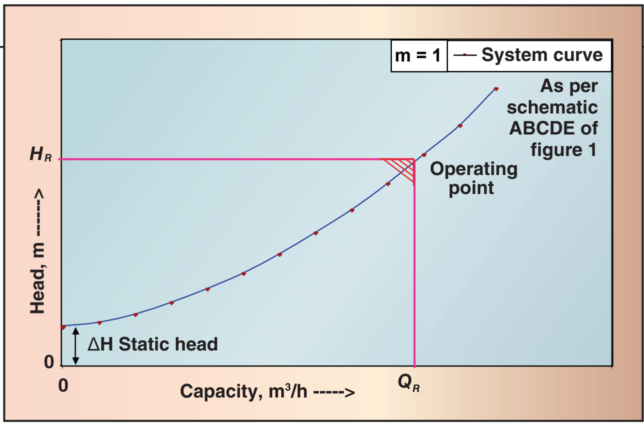

FIGURE 2. In Type 1 pumping systems, the pump will be operated only at one point (m = 1), with required head H_R at capacity = Q_R. Both options — the use of VFD and the use of FFD — are possible to meet these requirements

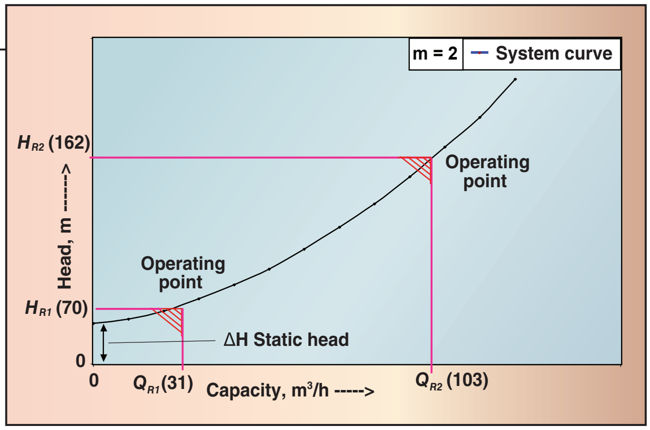

FIGURE 3. This system characteristic curve for Type 2 pumping system shows two different operating points (m=2), both of which lie on the same system characteristic curve, with required heads = H_{R1} and H_{R2} at respective capacities = Q_{R1} and Q_{R2}. In such a scenario, there can be more than two operating points (m>2). However, all operating points will be lying on same characteristic curves. Such requirements can be best accommodated by the use of a VFD

speed (N_{MAX}) with predetermined increments (say, 1 rpm), is then applied to the segments.

First, one of the segments is considered, and using Affinity Laws (discussed below), another performance curve is generated at (to start) minimum speed. Specifically, a simple quadratic equation is used to define this segment of the performance curve. The quadratic equation for the segment is then used to check if the required duty point lies on the segment or not.

If the duty point lies on the segment, then the speed corresponding to this particular curve is established as the matching speed. Otherwise the second segment is checked in a similar way. If that segment does not match with the duty point, then the calculations are repeated for the next higher speeds (N_{MIN} +1, N_{MIN} + 2, and so on) until the matching speed is determined.

If there is no matching speed to achieve the required duty, then the model is not suitable to fit with a VFD and is thus rejected. The process is repeated for all the available models to list out those models that can be fitted with a VFD (box, page 42).

Take your time in deciding

Because of the potential advantages that may result from the use of a VFD, many users rush to implement such a system without conducting a thorough evaluation of its economic and technical viability. Efforts to carry out such a viability check require an evaluation of lifecycle costs (LCC) calculations [*2, 3*].

LCC calculations require technical-feasibility data related to, for instance, the number of units required, the pump and motor rating, and power consumption. The engineer must systematically analyze the hydraulic performance data for each pump model to evaluate the overall technical benefits and feasibility of the solution.

Ideally, end users should check a large number of pump models for technical feasibility (as discussed below in the case study), which will require the processing of a large amount of data.

In general, VFDs often prove ideal for systems with zero static head (closed systems) or those with relatively low static head. However, as the static head increases, the use of a VFD may lose its economical advantages [*2, 4*]. A novel method is discussed in Ref. [*4*] to study the effect of changes in static head. Similarly, VFDs may prove to be less ideal for systems with operating points at the same head but at different flows.

While these aforementioned rules-of-thumb are handy, they may not be sufficient to justify the selection of a VFD for a given application. By contrast, using the LCC analysis to identify the exact cutoff point to confirm VFD viability is a more reliable approach, as it takes into consideration all the operating conditions.

Some pump manufacturers and VFD suppliers may not be equipped with software to check VFD feasibility. Thus, many will not be able to carry out analysis for the redundant or existing pumps of some other manufacturer for VFD feasibility.

The algorithm described here can be used to guide the procurement of new pumps, as well. In addition to data related to existing pumps (including both those that are either already in operation or available as surplus), data related to new pumps from approved pump vendors can also be stored and used to check the feasibility of new purchases.

Using the algorithm, data related to the hydraulic performance of competing pumps that are offered by different approved vendors can quickly be analyzed, which may lead to more options, as discussed in the case study.

The literature [*1, 4*] provides flow charts and some discussion about the methodology behind VFD selection. However, these references do not provide a precise algorithm with the necessary equations and formulas to write a simple computer program to help pump end users evaluate potential scenarios for the need to develop an algorithm.

Pump system operating points

For the purpose of VFD selection, the pumping system can be classified into three types, whose requirements and constraints are described below:

Type 1. The pump and VFD system must cater to only one operating point (so that m = 1, where m = the number of operating points). The typical piping schematics and corresponding system-characteristics curve are shown in Figures 1 and 2. In this case, the required process capacity is Q_R and the corresponding system head is H_R. The valve settings, piping schematics, liquid levels and pressure acting on the liquid surface remains unchanged. Because this is a relatively simple pumping system, the use of fixed frequency drive

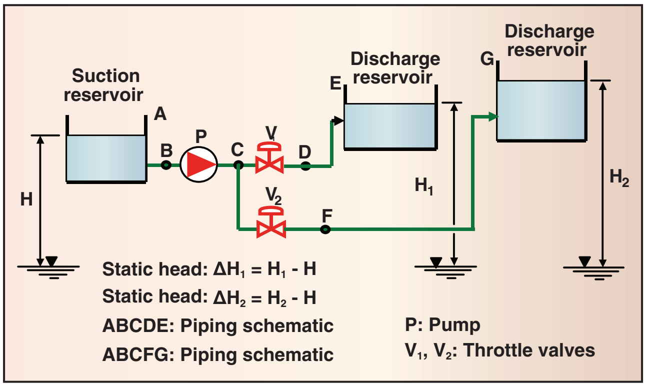

FIGURE 4. The piping array for a Type 3 pumping system is shown here. In a Type 3 pumping systems, two or more operating points all lie on different system characteristic curves (see Figure 5)

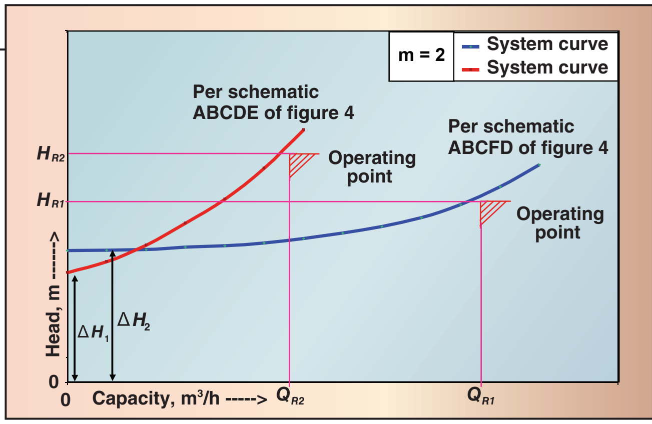

FIGURE 5. The system characteristic curves for a Type 3 pumping system shows two different operating points (m=2). Both lie on the different system-characteristic curves with required heads = H_{R1} and H_{R2} at respective capacities = Q_{R1} and Q_{R2}. There can be more than two operating points (m>2); however, all operating points will be lying on different characteristic curves. These requirements occur most frequently in real life situations and can be handled by the use of a VFD

(FFD) — for which a constant-speed electric motor driven at 50 or 60 Hz is typically used — is generally preferred, although the use of a VFD is possible.

Type 2. The pump and VFD system must cater to two or more operating points (so that $m \geq 2$). The typical piping schematics and corresponding system-characteristic curve for this scenario are depicted in Figure 1 and Figure 3. In this case, the process requirements change from one operating point to another (say, Q_{R1} to Q_{R2}, or vice versa). The operating points lie on the same system curve. The valve setting, piping schematics, liquid levels and pressure acting on the liquid surface remain unchanged.

Such requirements can usually be best handled by a VFD, as the use of flow-control-valve throttling to modulate the flow from Q_{R1} to Q_{R2} (or otherwise, per the process requirement) is eliminated.

The case study discussed in the box (p. 42) provides a typical example of a Type 2 application. In the absence of a VFD, the required changes in flow are achieved by throttling, but this approach is inherently inefficient and leads to energy loss.

Type 3. The pump and VFD system must cater to two or more operating points (so that $m \geq 2$). The operating points, however, lie on different system curves that are generated due to changes in the following system attributes:

- Valve setting
- Static head
- Piping schematics, say, from ABCDE to ABCFG (see Figure 4)
- A combination of any of the above factors

The typical piping schematics and corresponding system-characteristic curves are shown in Figures 4 and 5. In this case, the process requirements change from one operating point (say, Q_{R1}) to another (Q_{R2}), with corresponding system heads of H_{R1} and H_{R2}. Such requirements are more complex. However, they occur frequently in real-life situations and can usually be managed effectively by the addition of a VFD.

Required inputs

To use the algorithm to assist with VFD evaluation and compare competing pumping-system scenarios, the various types of data that must be gathered are discussed in this section.

First, data from hydraulic performance curves are collected and stored in the computer for any pumps for which the VFD feasibility is to be evaluated. Table 1 (Numbers 1 through 21) shows the database values that need to be gathered to use the algorithm. These details should be collected from the pump maker.

For existing pumps, the details are taken from the hydraulic performance curves, which are based on actual testing that is carried out by the vendor before the unit has been dispatched to the purchaser. For new purchases, the data are collected from the standard hydraulic-performance curves at the maximum impeller diameter at a speed corresponding to a 2-, 4- or 6-pole motor at 50 or 60 Hz. These standard performance curves are available from the pump manufactuers's literature.

After the details described above are gathered, the required operating point(s) (marked as m on the system curves), and, as detailed in Table 1 (values Number 22 through 25), are gathered into the database.

Assumptions for the algorithm

The algorithm relies on the following assumptions:

1. According to the Affinity Laws, flow (Q) and head (H) are assumed to be proportional to speed (N) and speed squared (N^2), respectively, for Q-H characteristics from the minimum continuous stable flow (Q_{MCSF}) to the maximum permissible flow (Q_{MAX}). It should be noted that the Affinity Laws are most accurately applicable for flows close to the pump's best efficiency point (BEP) flow Q_{BEP}, and can deviate slightly as flow values move away from BEP. This slight deviation, usually on the order of 3 to 4 percentage points, is neglected for calculation purposes.
2. It is known that the pump efficiency can change with respect to speed. This change can be up to 4 percentage points. This change is also neglected for calculation purposes. (It should be noted that there is no universally accepted way for the accurate prediction of deviations in value predicted by the Affinity Laws and change in efficiency with respect to speed.)
3. The pump efficiency read from the pump's flow-versus-efficiency curve is used to calculate the power input to the pump (instead of reading the pump input power directly from the

TABLE 1. VALUES TO BE GATHERED TO EVALUATE COMPETING PUMPING SCENARIOS

Item	Variable (**)	Details
1	n	Number of pump models for which the details below are available
2	*pump*	Pump model designation as per the vendor (such as 80 X 360)
3	D_2, mm	Impeller diameter at which laboratory test results are available. If laboratory test results are not available, then refer to standard curve from the pump manufacturer's book for a particular diameter. If pump manufacturer's data are to be stored for new purchase, then refer to impeller maximum diameter
4	N, rpm	Speed at which standard laboratory tests results are available
5	Q_{BEP}, m^3/h	Flow at best efficiency point (*BEP*)
6	H_{BEP}, m	Head, corresponding to Q_{BEP}
7	*BEP*, %	Best efficiency, corresponding to Q_{BEP}
8	Q_{MCSF}, m^3/h	Minimum continuous stable flow
9	H_{MCSF}, m	Head, corresponding to Q_{MCSF}
10	BEP_{MCSF}, %	Efficiency, corresponding to Q_{MCSF}
11	Q_{60}, m^3/h	60% of Q_{BEP} flow (If Q_{60} is close to Q_{MCSF} then Q_{60} is selected as an average of Q_{MCSF} and Q_{BEP})
12	H_{60}, m	Head, corresponding to Q_{60}
13	BEP_{60}, %	Efficiency, corresponding to Q_{60}
14	Q_{110}, m^3/h	110% of Q_{BEP} flow (If Q_{MAX} is close to Q_{110} then Q_{110} is selected as an average of Q_{MAX} and Q_{BEP})
15	H_{110}, m	Head, corresponding to Q_{110}
16	BEP_{110} %	Efficiency at Q_{110}
17	Q_{MAX}, m^3/h	Maximum permissible flow
18	H_{MAX}, m	Head, corresponding to Q_{MAX}
19	BEP_{MAX}, %	Efficiency at Q_{MAX}
20	N_{MAX}, rpm*	Maximum permissible speed for the given pump model
21	N_{MIN}, rpm*	Minimum permissible speed for the given pump model
22	m	Number of operating point(s) at which the pump is expected to run, with the details listed in Items 23, 24 and 25 for each operating point
23	Q_R, m^3/h	Required capacity
24	H_R, m	Required head corresponding to rated capacity
25	*Sp Gr*	Specific gravity

* These values are to be collected from the design department of the pump manufacturer, as they are not mentioned in standard performance curves.
** Units of measurement are shown for individual attributes.

pump's flow-versus-power-input characteristics curve). This is justified, as the pump efficiency curve nature is well-known (that is, it follows a continuous rise from zero flow to flow at *BEP*, and then decreases continuously for flow greater than flow at *BEP*), and the pump efficiency curve is independent of the density of liquid being pumped. Plus, the industry practice is to refer to the efficiency curve as it is easy to read and interpolate.

4. The *H-Q* characteristics can be expressed using the quadratic Equations (1) and (2) given below:

$$h = An^2 + Bnq + Cq^2 \quad (1)$$

Where:

h = head, m
n = rotational speed, rpm)
q = flow, m^3/h
A, B and C = constants for a given pump, impeller, and speed

For the typical case of a pump capacity operating at constant speed, the above equation can be written as standard quadratic equation.

$$h = a + bq + cq^2 \quad (2)$$

The constants a, b and c are for a given speed [*5*]. The range from minimal continuous stable flow to maximum permissible flow (Q_{MCSF} to Q_{MAX}) is chosen because the nature of the *H-Q* curve in this region for most machines usually rises continuously (pump head, *H*, is continuously increasing with decreases in pump flow). This known variation makes curve fitting simple. This is the usual range for pump selection.

This portion of the *H-Q* curve is further divided into two segments — the first from Q_{MCSF} to Q_{BEP}, and the second segment from Q_{BEP} to Q_{MAX}. The goal is to get better curve fit and also to take into account the change in slope of the *Q*-Efficiency characteristics after Q_{BEP} (that is, the decrease in efficiency with flow after *BEP*).

The efficiency variation from Q_{MCSF} to Q_{MAX} can be expressed using quadratic Equation (2) for the two segments mentioned above. The constants used in the quadratic equations for first segment (from Q_{MCSF} to Q_{BEP}) are calculated using Q_{MCSF}, Q_{60} and Q_{BEP} and corresponding head and efficiency values for a given speed. The constants used in the quadratic equations for the second segment (from Q_{BEP} to Q_{MAX}) are calculated using Q_{BEP}, Q_{110} and Q_{MAX} and corresponding head and efficiency values for the speed used for the first segment.

The algorithm

The specific steps in the algorithm are shown here:

Step 1. The data mentioned in Table 1 for the available pump model(s) being evaluated are gathered and stored in the computer, per the requirements of the programming language. For the given operating points (Q_R, H_R and *SpGr*), the feasibility of using the first model for which data are stored in Table 1 is checked, using the iterative calculations described in the following steps.

Step 2. The iterative calculations for selection start with generating the first segment of the *Q-H* curve (from Q_{MCSF} to Q_{BEP}) at minimum speed, N_{MIN}, for the first model being considered, using data stored in the computer data bank.

The three points (Q_{MCSF}, Q_{60} and Q_{BEP}) required to generate the first segment (Q_{MCSF} to Q_{BEP}) at speed N_{MIN} are calculated using the Affinity Laws to points Q_{MCSF}, Q_{60} and Q_{BEP} that are available in the data bank at speed N (see Table 1). The quadratic equation based on these three points is used to define the first segment at speed N_{MIN}. The head for the required flow Q_R is calculated using the quadratic equation and is compared with the required head H_R. Then, the second segment is checked in the same way. If the calculated head is within 1% of H_R (or a different limit chosen by the user) on any one of the segments, then the speed is taken as VFD speed.

Step 3. If matching is not within 1% (or a different limit chosen by the user), then the speed is increased by a small increment, say 1 rpm, and the next iteration is carried out for speed = (N_{MIN} +1).

Step 4. The process is continued until

CASE STUDY

The following case study relates to a naphtha splitter application. This study involves the purchase of a new pump, not the rerating of an existing or redundant one. Nevertheless, this case study demonstrates the efficacy of the algorithm discussed here for identifying the best pump models and determining whether or not the use of a VFD is warranted, after processing a large volume of data to support proper selection. The input data (attributes 1 through 21 of Table 1) for this case are based on standard pump series from two of the approved vendors.

The pump needed by the facility must accommodate two flows: 103 m^3/h at system head of 162 m, and 31 m^3/h at system head of 70 m (Figure 3). While the pump must be operated at a flowrate of 31 m^3/h most of the time, operation at 103 m^3/h for smaller, periodic intervals, is also required.

The exact operating hours for individual duty are required to calculate LCC. The computer program based on the algorithm checked all the pump models available in the data bank and identified 13 possible options with VFD. These are shown as item Numbers 5 to 17 in Table 2.

Table 2 shows all of the possible equipment scenarios — both with and without a VFD — that were identified here. The data marked with an asterisk refers to duty parameters that can be achieved by throttling the flow-control valve, while the data marked with a double asterisk represent the rated duty parameters required for pump selection.

In Table 2, Option 4 (using a 37-kW motor) is taken as the benchmark for comparison. The pumping liquid's specific gravity is 0.63.

The higher flow requirement of 103 m^3/h can be achieved in several ways — by selecting rated flow of 34 m^3/h (via three pumps in parallel), or 51.5 m^3/h (via two pumps in parallel), or 103 m^3/h (single pump operation).The flow of 31 m^3/h can be achieved with a single pump.

The scenarios that required FFD versus VFD to achieve these flows are also tabulated in Table 2. The VFD and corresponding motor were selected following a discussion with the VFD manufacturer's technical representative [9]. For the purpose of comparing potential power savings among the competing options (the last column of Table 2), Option 4 was taken as a benchmark, although any of the options could be used as the benchmark for such a comparison. The negative sign shows power saving, while a lack of a negative sign represents excess power consumption with respect to the benchmark value.

From the options for FFD (Options 1 to 4, Table 2), it is clear that to achieve the flowrate of 31 m^3/h, the single pump will operate at a head considerably higher than 70 m, which represents energy loss during throttling.

The options for a pump scenarios involving a VFD (Options 5 to 17, Table 2) show that for the same flowrate, the operation at system head of 70 m is possible, with substantial savings indicated by the negative sign. Thus, it is clear that for flowrate of 31 m^3/h the VFD provides increased energy efficiency.

Looking at impressive savings of 14.95 kW (Option 5 and 14, Table 2), the engineer may be tempted to recommend the same, however, an overall review including other flowrates is essential. For instance, for the higher flow requirement of 103 m^3/h, we do not see very encouraging results with the addition of a VFD, except for Option 11 and 13 ,where savings of 3.89 and 0.4 kW, respectively, are observed.

As noted in the main text, all options that are potentially viable from a technical standpoint should also be checked for economical viability as well, using the LCC analysis methodology; while LCC analysis is not discussed here, it is described in Ref. *3*. When carrying out LCC analysis for cases involving operation at the same or different flows (here 31 m^3/h and 103 m^3/h), an estimate of the number of hours of operation for each flow is critical to carry out the correct estimation of energy consumption.

Due to some specific constraints, engineers at the naphtha splitter described here ended up selecting Option 4 (Table 2), which entailed fixed-frequency operation (that is, no VFD). Nevertheless,

the matching speed or N_{MAX} — whichever comes first — is reached. If the matching speed is not available within the range of N_{MIN} to N_{MAX} that is applicable for the pump model being considered, then the use of a VFD will not be suitable for this pump model.

Step 5. Once the matching speed has been established, the flow-versus-efficiency curve is plotted for the matching speed. From this curve, using quadratic equations for segments, the efficiency value for the required flow is calculated, and the same is used to calculate the power input to the pump.

Step 6. If there is more than one operating point ($m \geq 2$, as shown in Figures 3 and 5), then the feasibility of using the same pump model is checked for all of the operating points, following Steps 2 through 7.

Step 7. After checking the feasibility of the first pump model for all the operating point(s), the process is repeated for the rest of the models that are under consideration (that is, the pumps whose data are available in the data bank).

Step 8. The pump models that can best cover the duty parameters are tabulated as output.

Finally, once the candidate pump models have been identified using this methodology, the compatability of using a VFD for each of those pump

Authors

D. K. Shukla is the senior vice-president with Essar Oil Ltd, (Essar Oil Ltd., Refinery Division, Essar House, 1st Floor, 34 KM Jamnagar Okha Highway, Vadinar 361 305, Gujrat, India.; Phone: 0091-2833 661 444; Mobile: +91 9819730390; E-mail: Dhirendra.Shukla@essar.com). He has more than 30 years of experience in process and systems engineering in the hydrocarbon processing industries, including oil-and-gas production facilities, and petroleum refining and petrochemical processes. His previous experience includes working with Engineers India Ltd. (New Delhi), M.W. Kellogg (Houston) and BOC Gases (in both Murray Hill, N.J., and Guildford, U.K.).

Deepak K Chaware is the rotating equipment engineer with Essar Oil Ltd. (Essar Oil Ltd., Refinery Division, Essar House, 1st Floor, 34 KM Jamnagar Okha Highway, Vadinar 361 305, Gujrat, India.; Phone: 0091-2833 661 444; Mobile: +91 9909992483 E-mail: Deepak.Chaware@essar.com). He received an M.Tech degree in mechanical engineering from Indian Institute of Technology (Chennai). He has more than 25 years of experience in the field of rotating equipment design, testing and selection. He has worked with several leading pump manufacturers, including Jyoti Ltd. India, Sulzer Pumps India Ltd., and KSB Pumps India Ltd.

Rajkumar B. Swamy is the senior process engineer with Litwin PEL LLC (Litwin PEL LLC, Emdad Complex, P.O. Box: 44715, Mussafah, Abu Dhabi, U.A.E; Phone: 00971-2-5070121; Fax: 00971-2-5516254; E-mail: Rajkumar.SWAMY@litwinme.ae). He has more than ten years of experience in the field of process and system engineering in petroleum refineries, oil-and-gas, and petrochemical complexes. He holds a graduate degree in chemical engineering from Gulbarga University (Karnataka, India). Prior to joining Litwin, his previous experience included working with Foster Wheeler Asia Pacific Pte Ltd. (Singapore), Reliance Engineering Associates Private Ltd. (Jamnagar, India) and Hindustan Petroleum Corporation Ltd. Mumbai Refinery (India).

TABLE 2. A COMPARISON OF THE FFD AND VFD OPTIONS

Option	Drive	No. of pumps = working + standby	Duty parameter			Pump model	Pump efficiency, %	BkW† / pump	Proposed motor rating, kW	Motor efficiency, %	VFD efficiency, %	Electric input / pump, kW	Total power, kW	Power saving, kW
			Q, m^3/h	H, m	Speed, rpm									
1	FFD	2 = 1 + 1*	31	164	2,900	80x360	34.00	25.71	37	92	100	27.95	27.95	4.77
		2 = 2 + 0**	51.5	162	2,900		50.00	28.69	37	92	100	31.18	62.37	6.68
2	FFD	2 = 1 + 1*	31	167	2,900	100x360	22.00	40.46	75	91	100	44.46	44.46	21.28
		2 = 1 + 1**	103	162	2,900		58.00	49.47	75	91	100	54.36	54.36	-1.33
3	FFD	3 = 1 + 2*	31	163	2,900	80x360	34.00	25.55	37	92	100	27.78	27.78	4.60
		3 = 3 + 0**	34	162	2,900		36.00	26.31	37	92	100	28.60	85.79	30.10
4	FFD	2 = 1 + 1*	31	168	2,950	80X50E	42.00	21.32	37	92	100	23.18	23.18	0.00
		2 = 2 + 0**	51.5	162	2,950		56.00	25.62	37	92	100	27.84	55.69	0.00
5	VFD	2 = 1 + 1	31	70	2,260	50X280	52.00	7.18	45	89	98	8.23	8.23	-14.95
		2 = 2 + 0	51.5	162	3,452		54.00	26.57	45	89	98	30.46	60.92	5.23
6	VFD	2 = 1 + 1	31	70	1,928	50X360	44.00	8.48	45	89	98	9.72	9.72	-13.46
		2 = 2 + 0	51.5	162	2,948		46.50	30.85	45	89	98	35.37	70.74	15.05
7	VFD	2 = 1 + 1	31	70	1,493	50X450	43.20	8.64	55	89	98	9.90	9.90	-13.28
		2 = 2 + 0	51.5	162	2,297		43.70	32.83	55	89	98	37.64	75.27	19.58
8	VFD	2 = 1 + 1	31	70	2,247	80X280	44.50	8.38	55	89	98	9.61	9.61	-13.57
		2 = 2 + 0	51.5	162	3,424		48.00	29.89	55	89	98	34.27	68.53	12.84
9	VFD	2 = 1 + 1	31	70	1,820	80x360	44.00	8.48	55	89	98	9.72	9.72	-13.46
		2 = 2 + 0	51.5	162	2,769		46.00	31.19	55	89	98	35.76	71.51	15.82
10	VFD	2 = 1 + 1	31	70	1,528	80X450	40.80	9.15	55	89	98	10.49	10.49	-12.69
		2 = 2 + 0	51.5	162	2,331		43.00	33.36	55	89	98	38.25	76.50	20.81
11	VFD	2 = 1 + 1	31	70	2,247	80X280	44.50	8.38	90	89	98	9.61	9.61	-13.57
		2 = 1 + 1	103	162	3,547		63.50	45.18	90	89	98	51.80	51.80	-3.89
12	VFD	2 = 1 + 1	31	70	1,820	80X360	44.00	8.48	75	89	98	9.72	9.72	-13.46
		2 = 1 + 1	103	162	2,890		58.20	49.30	75	89	98	56.52	56.52	0.83
13	VFD	2 = 1 + 1	31	70	1,528	80X450	40.80	9.15	75	89	98	10.49	10.49	-12.69
		2 = 1 + 1	103	162	2,410		59.50	48.22	75	89	98	55.29	55.29	-0.40
14	VFD	3 = 1 + 2	31	70	2,260	50X280	52.00	7.18	37	89	98	8.23	8.23	-14.95
		3 = 3 + 0	34	162	3,413		44.00	21.52	37	89	98	24.68	74.04	18.35
15	VFD	3 = 1 + 2	31	70	1,928	50X360	45.00	8.29	37	89	98	9.51	9.51	-13.67
		3 = 3 + 0	34	162	2,897		38.00	24.92	37	89	98	28.58	85.73	30.04
16	VFD	3 = 1 + 2	31	70	1,493	50X450	43.20	8.64	37	89	98	9.90	9.90	-13.28
		3 = 3 + 0	34	162	2,225		36.00	26.31	37	89	98	30.16	90.49	34.80
17	VFD	3 = 1 + 2	31	70	1,528	80X450	40.80	9.15	45	89	98	10.49	10.49	-12.69
		3 = 3 + 0	34	162	2,304		31.00	30.55	45	89	98	35.03	105.08	49.39

* Achieved by throttling. ** Rated duty for pump selection. VFD=Variable frequency drive FFD=Fixed-frequency drive. Specific gravity = 0.63 Option 4, which was ultimately selected with 37-kW motor, was taken as the datum for calculating power saving. "-" A negative sign indicates power saving, while the absence of the sign indicates power loss. † BkW = brake kilowatt (similar to brake horsepower); BkW is used as we are using the meter-kilogram- second (MPS) system, not the foot-pound-second (FPS) system.

models will need to be verified by the VFD, pump and motor vendors.

From the procedure described above, it is clear that selecting VFD for Case 1 (m = 1, Figure 1) will be relatively simple compared to Case 2 and Case 3 ($m \geq 2$, Figures 3 and 5). Selection for Case 3 will be more difficult, as a single pump catering to the number of operating points, lying on different system curves, with maximum efficiency may not be easily available. Under such circumstances, the user will likely be forced to select the pump that offers optimum efficiency, as achieving the highest efficiency for all operating points with a single pump is not possible.

The LCC analysis is carried out for each of the selected models using the method mentioned in Ref. *3*. Selection is then finalized taking into consideration the advantages, disadvantages, operational issues, constraints and problems [*1, 6, 7*] related to the addition of a VFD. It is essential that the feasibility of the selected pump models for the new operating conditions be checked. The checklist mentioned in Ref. *8* is a useful tool for doing so. ■

Edited by Suzanne Shelley

Acknowledgement

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The 'BIST' In Electronic Valve Actuators

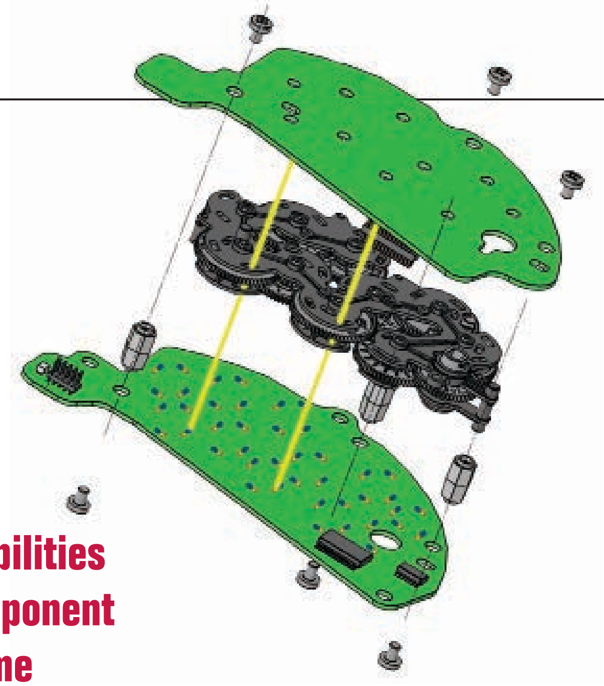

FIGURE 1. The optical absolute-encoder wheel has barriers at certain degreed positions that can block the light stream from the receiver

Smart actuators designed with BIST capabilities allow rapid identification of potential component failure, reduced operational downtime and increased overall plant safety

Earnest Carey, Jr.
Flowserve, Flow Control Division

For valves operating in hazardous environments, certification testing is critical to ensure the reliability and safety of the equipment. But this testing process has historically required facilities to shut down and sacrifice valuable production hours to check each valve. Built-in self-test (BIST) capabilities in smart, electronic valve actuators were developed in response to these testing challenges. This article examines how BIST simplifies valve testing and reduces the cost, while increasing the level of confidence in valve and actuator safety.

Safety standards and ratings

Before exploring how BIST can increase safety, it is important to know how safety standards for plant operations are changing. Safety integrity levels (SILs) for safety instrumented systems (SIS) are becoming the universal standard for measuring plant functional safety. SIL is a safety rating of various components of a facility that include SIS, which provide controls installed for the purpose of preventing a failure.

SIL uses a four-level rating system. A third-party organization evaluates an installed component and its hardware, considering such factors as redundant architectures, average repair time, and specific failure rates of all products and subsystems. The organization then assigns an SIL rating of one through four, with the SIL-4 rating being the most reliable (for more on SIS and SIL, see Tolerable Risk, *Chem. Eng*. September 2007, pp. 69–74).

International Electrotechnical Commission (IEC) 61508 and IEC 61511 are examples of standards used to define SIL for a device or system. To reach a given SIL level, both hardware-safety-integrity and systematic-safety-integrity requirements must be satisfied. The IEC 61511 standard is used by end users in the chemical process industries (CPI) to quantify hazards and risk in their plants. IEC 61508 is used by manufacturers to determine what type of loop a given device can be installed into, based on failure modes effects and diagnostic anaylsis (FMEDA) and historical failure rates (for more on failure-rate determination for mechanical components, see Mechanical Failure-Rate Data for Low-Demand Applications, *Chem. Eng*. October 2007, pp. 83–87).

SIS are systems containing instrumentation or controls installed for the purpose of preventing or mitigating a failure. SIS achieve these goals either by emergency shutdown or diverting the hazard. SIL levels for SIS are defined by international standards, such as IEC 61508, IEC 61511, and Instrumentation Systems and Automation Society (ISA) 84.01-2003.

According to IEC 61508 Part 4 (1998), dangerous failures have the potential to put safety-related systems in a hazardous or fail-to-function state. State-of-the-art smart electric valve actuators, often selected for critical systems due to their flexible configuration capabilities, can be introduced into plant systems to monitor and diagnose potential situations that could compromise the overall SIS level.

BIST's role in safety

The introduction of electronics to plant systems increases the level of sophistication required for troubleshooting these devices. Moreover, digital electronics-based devices can become unreliable when electronic faults, component failures or faulty signals occur.

To counter these limitations, some high-tech electronic-actuator designs include BIST capabilities. BIST reduces the cost and time associated with complex testing equipment and trial-and-error methodology.

An actuator designed with BIST has test functionality embedded in the device itself and is capable of communicating a critical component's actual state compared to its expected state. Any deviation from expected values will be reported to the user, along with an analysis correlating the deviation to a failed component or subsystem. Smart actuators with

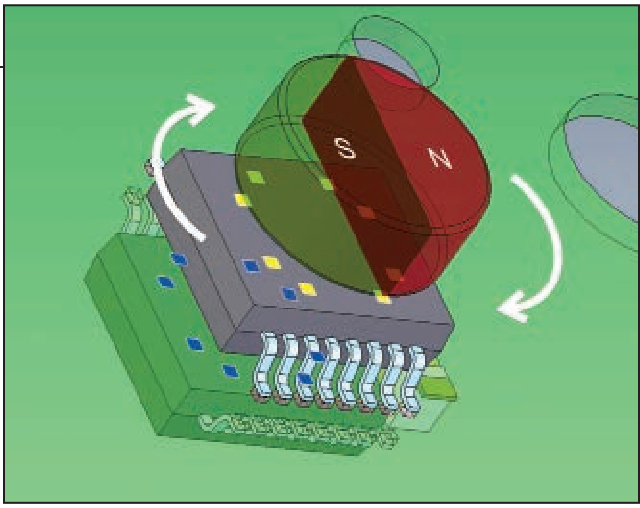

FIGURE 2. Hall-effect devices are excited by a contactless magnet. Ideally, these components are integrated into a microchip

BIST diagnostic capabilities communicate the status of major components to the user via the actuator's liquid crystal display (LCD) screen, over a digital network, or wirelessly via a Bluetooth link.

In contrast, maintenance crews at plants operating valves that do not have actuators with BIST capabilities must deduce which module is causing the problem when a test failure occurs. The valve or actuator is often disassembled and suspect parts are replaced before being reassembled and tested again. Sometimes it is necessary for this time-consuming process to be repeated several times until the valve or actuator performs satisfactorily.

Partial stroke tests. Plants have mitigated this trial and error methodology by performing partial stroke tests (PST) on certain valves, especially in critical installations. PST, one of the features that can be configured into a smart actuator, provides plant operators the confidence that block valves will operate when called upon to ensure safe shutdown in an emergency situation. The test involves closing (or opening) the block valve partially, usually 10 to 30%, to ensure the valve is not immovable when a true emergency occurs.

Running a PST takes up valuable time that could be spent on other maintenance activities. By installing an actuator with BIST capabilities, fewer PSTs need to be performed because the user has confidence that the selected actuator will operate when required. The lower the number of PSTs required, the less potential that an emergency shutdown event coincides with a scheduled PST. Any decrease in operation of an actuator also contributes to longevity.

Failure in time. What are some of the reasons for installing smart actuators with BIST capabilities that meet the requirements of IEC 61508? One reason for utilizing smart actuators with BIST is that these actuators' calculated "failure in time (FIT)" has been analyzed and evaluated. FIT is the number of failures that can be expected in one billion hours of operation. A lower FIT rate means plants are safer because the reliability of the equipment is improved.

FIT can be calculated by performing a failure modes, effects and criticality analysis (FMECA), which is a structured qualitative analysis to identify potential failure modes, their causes and their effects. This analysis builds on the FMEDA, which was created in the late 1980s due to a need for a measurement of automatic diagnostic capabilities such as BIST. The FMECA evaluates quantitative failure data for all components being analyzed and the ability of the system to detect internal failures via automatic online diagnostics.

Safe failure fraction. Another reason for selecting actuators with BIST capabilities is that these actuators' safe failure fraction (SFF) has been analyzed and determined. SFF is the fraction of the overall failure rate of a device that results in either a safe fault or a diagnosed unsafe fault being detected. BIST can not only improve the calculated FIT rate of an actuator but can also lower the SFF.

Decreasing the FIT and the SFF not only improves plant safety, but also decreases the number of PST that must be performed for certain valves over a defined period of time. A lower FIT and the resulting SFF calculation means the safety level for a given device improves. These values correlate to an actuator's ability to perform when called upon to do so.

BIST design considerations

Not all BIST designs are created equal. Some smart actuators offer only a rudimentary level of reporting and are limited to vague diagnostic messages, such as "hardware failure" and "lost signal" — or they may not respond to the user at all.

There are a number of designs that ensure a specific device was developed with BIST characteristics. One way to predict potential problems before they occur is to design redundant paths for position-sensing circuits. This technology in electronic valve actuators can be designed into absolute encoders that sense the valve's position. Position of the actuator is transmitted via a mechanical coupling (gear) from the drive sleeve to the absolute encoder.

One design of an absolute encoder for use in a smart actuator can include optical devices for the purpose of isolating the device from electrical noise interference. These optical components are typically light-emitting and receiving devices. An emitter shoots out a light stream, which in turn is received by a corresponding receiver, terminating the light stream. This stream of light is passed through a wheel designed with precise radial slots, permitting light to be transmitted through the slot to a receiver. The wheel also has barriers at certain degreed positions that can block the light stream from the receiver. As the encoder wheel rotates, the light stream is "on" when it passes through the slots or is "off" when interrupted by the barrier (Figure 1).

The combination of light on and light off develops a digital signature. This signature is then duplicated across a number of wheels with slots and barriers. The rotation of the wheels and the on-off light sequences occur at specifically timed intervals. The ensuing digital values calculate the position of the valve via the electronic actuator. Extremely high resolution is achievable using this technique.

Another method for BIST in an absolute encoder's design is to use Hall-effect devices that are excited by a contactless magnet. Ideally, these components would be integrated into a microchip. As the actuator turns, a mechanical coupling rotates the mag-

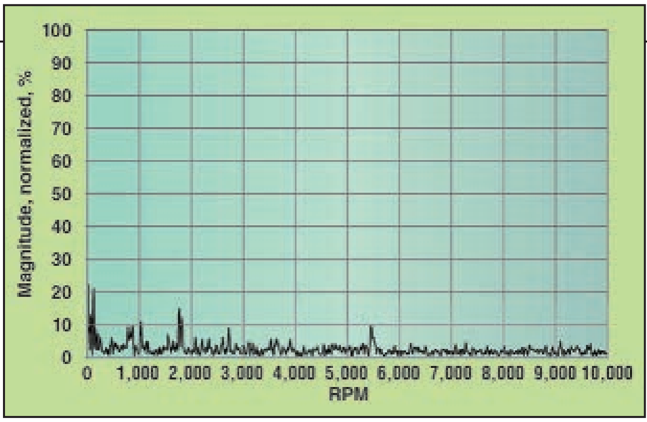

FIGURE 3. This fast Fourier-transform (FFT) chart is of a healthy, efficient actuator worm-gear set

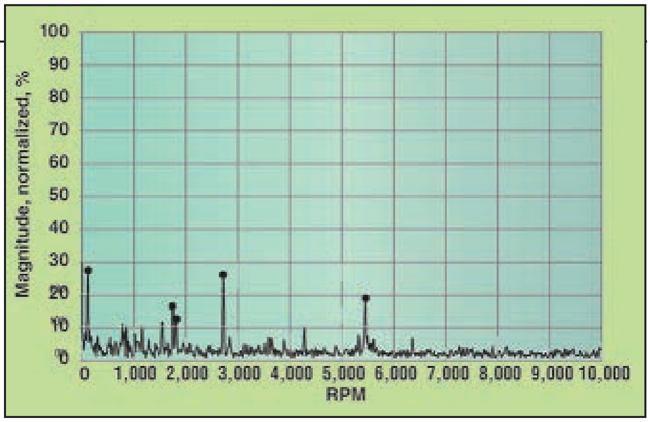

FIGURE 4. Peaks are seen on the FFT of an actuator exhibiting a specific component that is out of tolerance due to excessive wear

net about an array of several Hall-effect devices. When the magnet passes over a Hall-effect device, it causes a change in the electromagnetic field and a digital signature (on-off) is developed. This signature is duplicated across the array of Hall-effect devices at specifically timed intervals, resulting in digital values that calculate the position of the valve via the electronic actuator (Figure 2).

Redundancy. However, solid-state devices, even very robust ones, sometimes fail. This is true of the emitters and receivers and Hall-effect devices. A robust design for BIST should include circuit redundancy — parallel pairs of emitters and receivers for an optical encoder and a secondary microchip for Hall-effect designed encoders.

In the unlikely event that an emitter or receiver fails in the optical absolute encoder, the corresponding and parallel emitter or receiver would continue to operate. Should one of the devices fail, an error message would be transmitted to the actuator's LCD screen and cause a fault in the control room if the actuator's monitor relay is used to status the valve. This error message can also be communicated over a digital network if the actuator is equipped with a fieldbus communication board. The duplication of the optical devices provides confidence to a user that safe operation of the valve can continue if its operation is of a critical nature. If both optical circuit pairs are compromised, the actuator will fail to perform, consequently resulting in "fail, no action."

In the BIST scenario for absolute encoders designed with Hall-effect components, circuit redundancy would include another microchip with an array of embedded Hall-effect devices. In the unlikely event that a Hall-effect device or microchip fails, the main board logic would switch position sensing to the other microchip, and the actuator would continue to operate. The failure would produce an error message and fault display in the same manner as an optically redundant absolute encoder.

The duplication of a second microchip with embedded Hall-effect devices provides confidence to a user that safe operation of the valve may continue if its operation is of a critical nature. If either the microchips or the Hall-effect device circuits are compromised, the actuator will result in "fail, no action." In addition to redundant on-board circuits, a true BIST design also allows the printed circuit board to be pre-tested before assembly, eliminating most defects before installation into the actuator. After installation into the field, if electronic defects are detected at any time, the actuator equipped with BIST can provide feedback, pinpointing the specific problem, allowing maintenance personnel to quickly recognize and replace only the failed module.

Fast Fourier-transform analysis. A robust BIST system should not only include circuit redundancy but also include embedded software developed with frequency-domain-analysis capabilities, a design enhancement for smart actuators that analyzes variations in torque, position or speed values at regular time intervals while the motor is engaged. The actuator then performs a fast Fourier-transform (FFT) analysis on the resulting data set to convert the information from the time domain to the frequency domain.

The resulting chart characteristics can be used to identify any components in the mechanical drive chain, valve or actuator that have failed or will fail in the near future. A healthy actuator will exhibit few variations, and the resulting FFT chart will be relatively flat (Figure 3). However, if any part of the mechanical drive train has been fabricated with a physical defect or degrades over time, the FFT will exhibit a plot with frequency peaks that can, depending on the frequency signature, be associated with a particular suspect part (Figure 4). This signature could indicate an issue within the actuator or the valve operated by the actuator.

Manufacturers collect and embed knowledge about critical components of the mechanical drive train into the actuator before shipping to a user, making it easy to correlate frequency spikes on the FFT chart to a given component. The information, downloaded and stored in the electronics package, allows the on-board CPU to derive whichever part of the drive components is contributing to a variation in the frequency response. Finally, the FFT chart can be wirelessly downloaded via a Bluetooth link to the user's asset management system, laptop or PDA for analysis. ■

Edited by Dorothy Lozowski

Author

Earnie Carey is the heavy-duty-actuation portfolio manager for Flowserve's Flow Control Division (5114 Woodall Road, Lynchburg, Va. 24502; Phone: 434–522–4107; Email: ECarey@Flowserve.com). He has been with Limitorque and Flowserve Corp. for 28 years in roles of increasing responsibility. Carey started his tenure as a test engineer involved with environmental qualifications of safety-related electric actuators in the 1980s. He moved to product development in the early 1990s and has been the product manager of Flowserve's smart actuator series, the MX, since 1998. He is also the product manager for the latest smart actuator from Flowserve Limitorque, the QX. Before coming to Limitorque, he was with Babcock and Wilcox in their Navy Nuclear Division as an engineering technologist for almost ten years.

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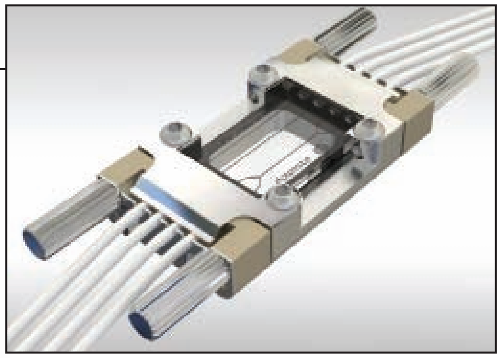

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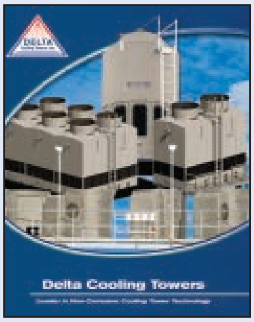

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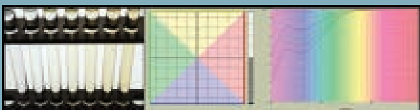

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24 Safety & Environmental
26 Other____________

EMPLOYEE SIZE

28 Less than 10 Employees
29 10 to 49 Employees
30 50 to 99 Employees
31 100 to 249 Employees
32 250 to 499 Employees
33 500 to 999 Employees
34 1,000 or more Employees

YOU RECOMMEND, SPECIFY, PURCHASE
(please circle all that apply)

40 Drying Equipment
41 Filtration/Separation Equipment
42 Heat Transfer/Energy Conservation Equipment
43 Instrumentation & Control Systems
44 Mixing, Blending Equipment
45 Motors, Motor Controls
46 Piping, Tubing, Fittings
47 Pollution Control Equipment & Systems
48 Pumps
49 Safety Equipment & Services
50 Size Reduction & Agglomeration Equipment
51 Solids Handling Equipment
52 Tanks, Vessels, Reactors
53 Valves
54 Engineering Computers/Software/Peripherals
55 Water Treatment Chemicals & Equipment
56 Hazardous Waste Management Systems
57 Chemicals & Raw Materials
58 Materials of Construction
59 Compressors

1	16	31	46	61	76	91	106	121	136	151	166	181	196	211	226	241	256	271	286	301	316	331	346	361	376	391	406	421	436	451	466	481	496	511	526	541	556	571	586
2	17	32	47	62	77	92	107	122	137	152	167	182	197	212	227	242	257	272	287	302	317	332	347	362	377	392	407	422	437	452	467	482	497	512	527	542	557	572	587
3	18	33	48	63	78	93	108	123	138	153	168	183	198	213	228	243	258	273	288	303	318	333	348	363	378	393	408	423	438	453	468	483	498	513	528	543	558	573	588
4	19	34	49	64	79	94	109	124	139	154	169	184	199	214	229	244	259	274	289	304	319	334	349	364	379	394	409	424	439	454	469	484	499	514	529	544	559	574	589
5	20	35	50	65	80	95	110	125	140	155	170	185	200	215	230	245	260	275	290	305	320	335	350	365	380	395	410	425	440	455	470	485	500	515	530	545	560	575	590
6	21	36	51	66	81	96	111	126	141	156	171	186	201	216	231	246	261	276	291	306	321	336	351	366	381	396	411	426	441	456	471	486	501	516	531	546	561	576	591
7	22	37	52	67	82	97	112	127	142	157	172	187	202	217	232	247	262	277	292	307	322	337	352	367	382	397	412	427	442	457	472	487	502	517	532	547	562	577	592
8	23	38	53	68	83	98	113	128	143	158	173	188	203	218	233	248	263	278	293	308	323	338	353	368	383	398	413	428	443	458	473	488	503	518	533	548	563	578	593
9	24	39	54	69	84	99	114	129	144	159	174	189	204	219	234	249	264	279	294	309	324	339	354	369	384	399	414	429	444	459	474	489	504	519	534	549	564	579	594
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11	26	41	56	71	86	101	116	131	146	161	176	191	206	221	236	251	266	281	296	311	326	341	356	371	386	401	416	431	446	461	476	491	506	521	536	551	566	581	596
12	27	42	57	72	87	102	117	132	147	162	177	192	207	222	237	252	267	282	297	312	327	342	357	372	387	402	417	432	447	462	477	492	507	522	537	552	567	582	597
13	28	43	58	73	88	103	118	133	148	163	178	193	208	223	238	253	268	283	298	313	328	343	358	373	388	403	418	433	448	463	478	493	508	523	538	553	568	583	598
14	29	44	59	74	89	104	119	134	149	164	179	194	209	224	239	254	269	284	299	314	329	344	359	374	389	404	419	434	449	464	479	494	509	524	539	554	569	584	599
15	30	45	60	75	90	105	120	135	150	165	180	195	210	225	240	255	270	285	300	315	330	345	360	375	390	405	420	435	450	465	480	495	510	525	540	555	570	585	600

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BUSINESS NEWS

PLANT WATCH

Outotec to deliver precious-metals plant in China

January 25, 2010 — Outotec Oy (Espoo, Finland; www.outotec.com) has signed a contract with Baiyin Non Ferrous Group for the design and delivery of a new precious metals plant in Gansu Province, China. The plant is expected to be operational during the first half of 2011, and it will treat 4,000 metric tons per year (m.t./yr) of both copper- and lead-anode slimes in a Kaldo furnace.

Topsøe wins contract with PetroPeru for three new plants

January 25, 2010 — Haldor Topsøe (Lyngby, Denmark; www.topsoe.com) has signed a contract supplying technologies for three new plants with petroleum-oil refiner, PetroPeru. The Topsøe technologies are part of a modernization project of the Talara refinery located in northern Peru. Topsøe will supply license, engineering, catalyst and proprietary equipment for: a hydrogen plant of 30-million scf/d; an ultra-low sulfur diesel hydrotreating plant for 41,000 bbl/d; and a plant for reduction of sulfur emissions producing 460 ton/d of sulfuric acid. The plants are planned to be onstream in 2015.

Lanxess builds a new membrane-filtration-technology plant in Germany

January 21, 2010 — Lanxess AG (Leverkusen, Germany; www.lanxess.com) is building a new chemical plant at its site in Bitterfeld, Germany. This marks the specialty chemicals group's move into a new segment of the water treatment business. Lanxess plans to invest a total of around €30 million to develop and produce membrane filtration technology in Bitterfeld. The State of Saxony-Anhalt is sponsoring this project by up to €6 million. Operation of a pilot-and-development phase for the new plant is expected toward the end of 2010, with the first products launched to the market in 2011.

Total and ConocoPhillips sanction Phase 2 of the Surmont Project

January 19, 2010 —Total (Courbevoie, France; www.total.com) and ConocoPhillips (Houston; www.conocophillips.com) have announced the sanction of the Surmont Phase 2 SAGD (steam assisted gravity drainage) development in Canada. The project, slated to begin initial construction in 2010, will increase Surmont's production capacity from 27,000 to 110,000 bbl/d of bitumen. The Surmont project, located in the Athabasca oil sands region, is operated by ConocoPhillips Canada and is a 50/50 joint venture with Total E&P Canada. Phase 2 is scheduled to begin production in early 2015. SAGD is a thermal production techology used to recover bitumen from the oil sands (for more on SAGD and oil sands, see Oil from Sand, *Chem. Eng.* pp. 19–22, February 2009).

Wacker to consolidate its production of pyrogenic silica

January 14, 2010 — Wacker Chemie AG (Munich, Germany; www.wacker.com) has announced that it is consolidating pyrogenic silica production in the context of previously announced structural-improvement measures at its Wacker Silicones division. As a result, Wacker plans to close its Kempten site during 2011. Kempten's production volumes will be transferred to Burghausen and Nünchritz, optimizing capacity utilization at these sites.

UOP is to receive a DOE award for a cellulose-to-fuel plant

January 13, 2010 — UOP LLC (Des Plaines, Ill.; www.uop.com) will receive a $25-million award from the U.S. Dept. of Energy (Washington, D.C.; www.energy.gov) to construct a demonstration plant for converting cellulosic biomass to transportation fuels. Scheduled to begin operations in 2014, the unit will be built at the Tesoro Corp. (San Antonio, Texas; www.tsocorp.com) refinery in Kapolei, Hawaii (for more, see p. 11).

Uhde to supply HCl-electrolysis plant to Yantai Juli

January 8, 2010 — Uhde GmbH (Dortmund, Germany; www.uhde.eu) has been awarded an engineering and procurement contract for the construction of a hydrochloric-acid-electrolysis plant by Yantai Juli Isocyanate Co., a Chinese manufacturer of polyurethane. The plant, with a production capacity of 100,000 ton/yr of HCl, will be constructed at Laiyang, Shandong Province, China, approximately 100 km north of Qingdao. Commissioning is scheduled for the end of 2011.

CB&I is awarded contracts from Jilin for ethylbenzene and styrene monomer plant

January 8, 2010 — CB&I (Chicago Bridge and Iron Co., The Hague, the Netherlands; www.cbi.com) has announced that Petrochina Jilin Petrochemical Co. (Jilin) has awarded a contract to Lummus Technology, a CB&I company, for the license and process design of a grassroots ethylbenzene and styrene monomer (EB/SM) plant in Jilin, China. The plant has a design capacity of 320,000 m.t./yr of styrene monomer and will utilize proprietary technologies provided by Lummus and UOP. The plant, expected to start up in 2011, is the second EB/SM plant awarded to Lummus Technology by Jilin.

Technip lands FEED contract for an ethylene plant in Venezuela

January 5, 2010 — Technip (Paris, France; www.technip.com) has been awarded, by Polimerica, a reimbursable contract to perform the front-end-engineering design (FEED) for a new ethylene plant. The plant, which will have a capacity of 1.3-million ton/yr, will be part of a new petrochemical complex to be built in Josè, Venezuela. The estimated overall investment for the complex will be around $3.2 billion. The FEED activities are scheduled to be completed by the 2nd Q 2011.

MERGERS AND ACQUISITIONS

Siemens expands dewatering solutions into mining market with acquisition

January 7, 2010 — By acquiring Industrial Process Machinery (IPM; Manchester, New Hampshire) Siemens is continuing to expand its dewatering-solutions offering for industrial applications. As of December 31, 2009, IPM is part of Siemens Water Technologies (Warrendale, Penn.; www.water.siemens.com), a business unit of the Siemens Industry Solutions Div. IPM will continue to operate out of its office in Manchester, N. H.

Lanxess acquires PTA product line from Clariant

January 6, 2010 — Specialty chemicals group, Lanxess AG (Leverkusen, Germany; www.lanxess.com), has acquired the Nipacide-PTAP product-line from Clariant (Muttenz, Switzerland; www.clariant.com) effective January 1, 2010. The active ingredient p-tert-amylphenol (PTAP) complements the phenolic active ingredients portfolio of Lanxess' Material Protection Products (MPP) business unit. The parties have agreed not to disclose financial details of the transaction. ■

Dorothy Lozowski

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

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Economic Indicators

2009 2008

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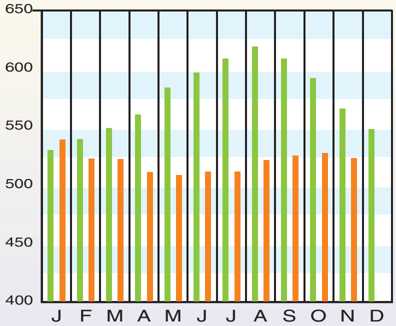
CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957-59 = 100)	Nov.'09 Prelim.	Oct.'09 Final	Nov.'08 Final
***CE* Index**	523.6	527.9	566.2
Equipment	618.0	623.6	681.3
Heat exchangers & tanks	556.1	567.0	655.8
Process machinery	601.1	605.5	641.0
Pipe, valves & fittings	768.2	768.9	831.8
Process instruments	413.5	409.8	415.6
Pumps & compressors	895.2	896.3	896.5
Electrical equipment	465.9	464.2	461.7
Structural supports & misc	624.2	636.5	718.0
Construction labor	329.6	331.7	326.4
Buildings	493.0	495.4	514.0
Engineering & supervision	343.8	344.6	350.6

Annual Index:
2001 = 394.3
2002 = 395.6
2003 = 402.0
2004 = 444.2
2005 = 468.2
2006 = 499.6
2007 = 525.4
2008 = 575.4

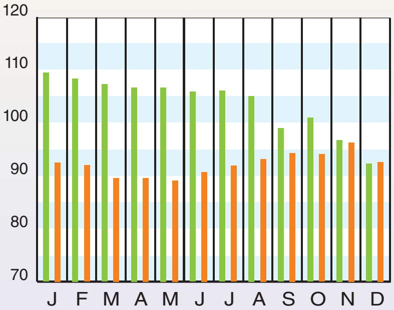


Starting with the April 2007 Final numbers, several of the data series for labor and compressors have been converted to accommodate series IDs that were discontinued by the U.S. Bureau of Labor Statistics

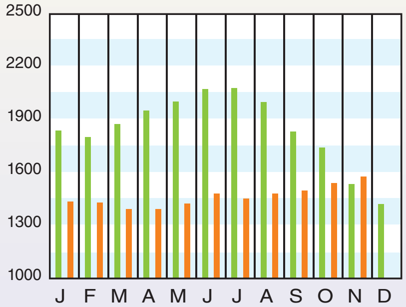
CURRENT BUSINESS INDICATORS

	LATEST			PREVIOUS						YEAR AGO		
CPI output index (2000 = 100)	Dec.'10	=	96.2	Nov.'10	=	96.3	Oct.'10	=	94.1	Dec.'09	=	92.3
CPI value of output, $ billions	Nov.'10	=	1,577.7	Oct.'10	=	1,540.6	Sep.'10	=	1,499.6	Nov.'09	=	1,535.2
CPI operating rate, %	Dec.'10	=	71.2	Nov.'10	=	71.2	Oct.'10	=	69.4	Dec.'09	=	67.1
Producer prices, industrial chemicals (1982 = 100)	Dec.'10	=	254.9	Nov.'10	=	251.3	Oct.'10	=	243.3	Dec.'09	=	219.3
Industrial Production in Manufacturing (2002=100)*	Dec.'10	=	98.7	Nov.'10	=	98.7	Oct.'10	=	97.8	Dec.'09	=	100.6
Hourly earnings index, chemical & allied products (1992 = 100)	Dec.'10	=	151.0	Nov.'10	=	151.6	Oct.'10	=	150.1	Dec.'09	=	143.9
Productivity index, chemicals & allied products (1992 = 100)	Dec.'10	=	138.6	Nov.'10	=	137.3	Oct.'10	=	136.5	Dec.'09	=	122.1

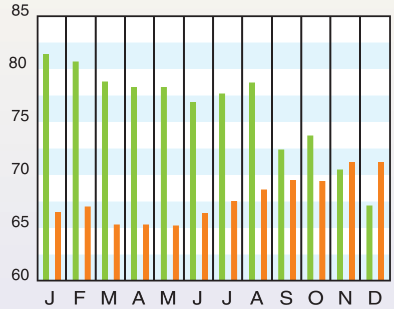
CPI OUTPUT INDEX (2000 = 100)



CPI OUTPUT VALUE ($ BILLIONS)



CPI OPERATING RATE (%)

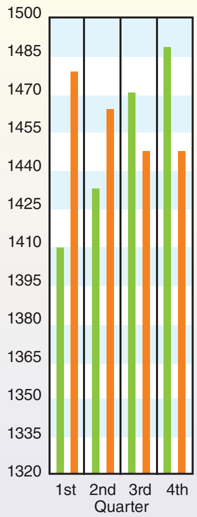


MARSHALL & SWIFT EQUIPMENT COST INDEX

(1926 = 100)	4th Q 2009	3rd Q 2009	2nd Q 2009	1st Q 2009	4th Q 2008
M & S INDEX	1,446.5	1,446.4	1,462.9	1,477.7	1,487.2
Process industries, average	1,511.9	1,515.1	1,534.2	1,553.2	1,561.2
Cement	1,508.2	1,509.7	1,532.5	1,551.1	1,553.4
Chemicals	1,483.1	1,485.8	1,504.8	1,523.8	1,533.7
Clay products	1,494.3	1,495.8	1,512.9	1,526.4	1,524.4
Glass	1,400.1	1,400.4	1,420.1	1,439.8	1,448.1
Paint	1,514.1	1,515.1	1,535.9	1,554.1	1,564.2
Paper	1,415.8	1,416.3	1,435.6	1,453.3	1,462.9
Petroleum products	1,617.6	1,625.2	1,643.5	1,663.6	1,668.9
Rubber	1,560.5	1,560.7	1,581.1	1,600.3	1,604.6
Related industries					
Electrical power	1,377.3	1,370.8	1,394.7	1,425.0	1,454.2
Mining, milling	1,548.1	1,547.6	1,562.9	1,573.0	1,567.5
Refrigeration	1,769.5	1,767.3	1,789.0	1,807.3	1,818.1
Steam power	1,470.8	1,471.4	1,490.8	1,509.3	1,521.9

Annual Index:

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



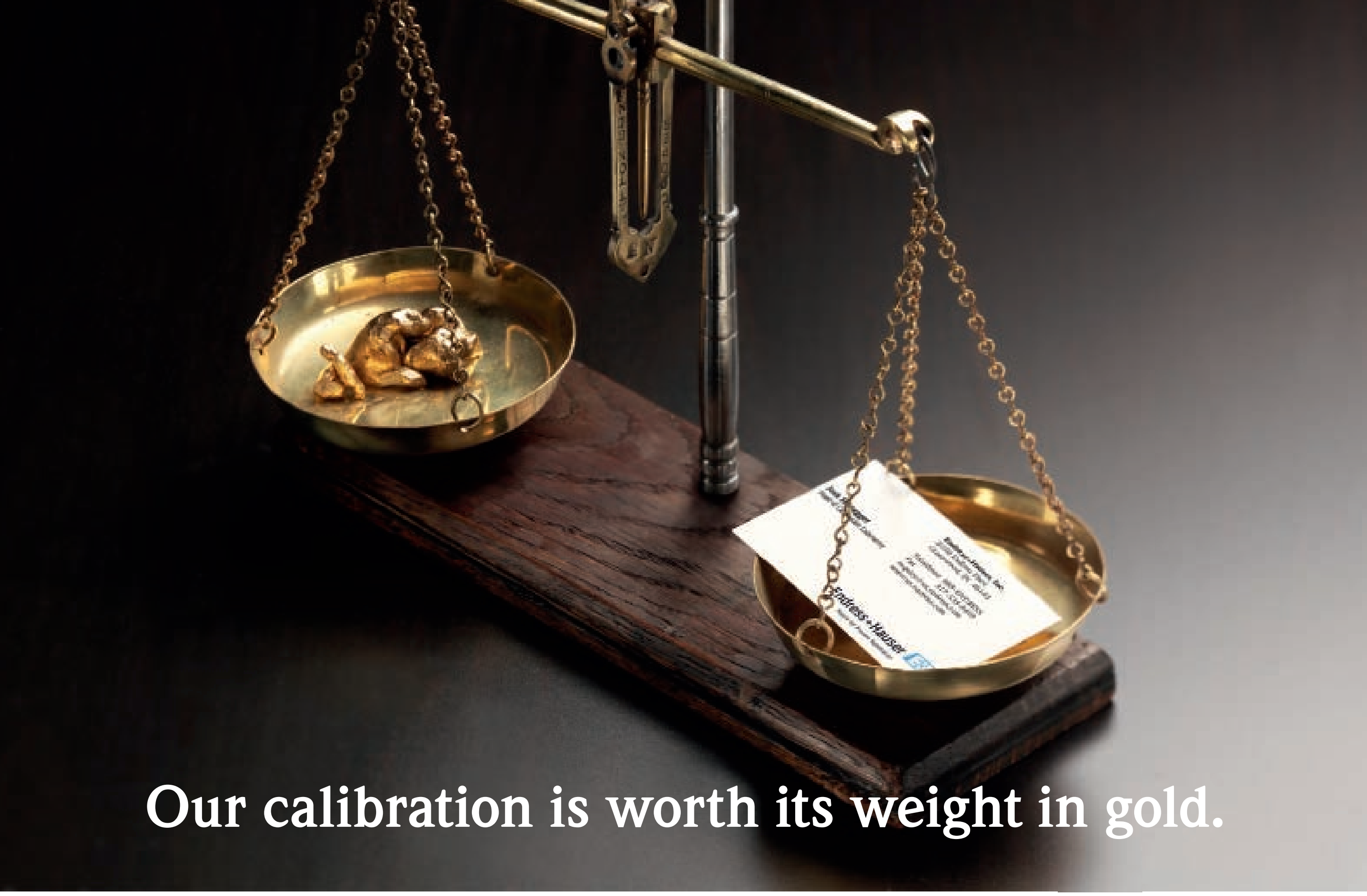
CURRENT TRENDS

With the data released in this issue, all of the major business indicators for the CPI have finally surpassed their year-over-year deficits, a significant milestone in transitioning from an economic recovery period and into one of economic growth.

Meanwhile, November capital equipment prices (as reflected in the *Chemical Engineering* Plant Cost Index) are back on track with a typical end-of-year decline, following an atypical increase from July to October.

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

Circle 2 on p. 54 or go to adlinks.che.com/29247-02



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