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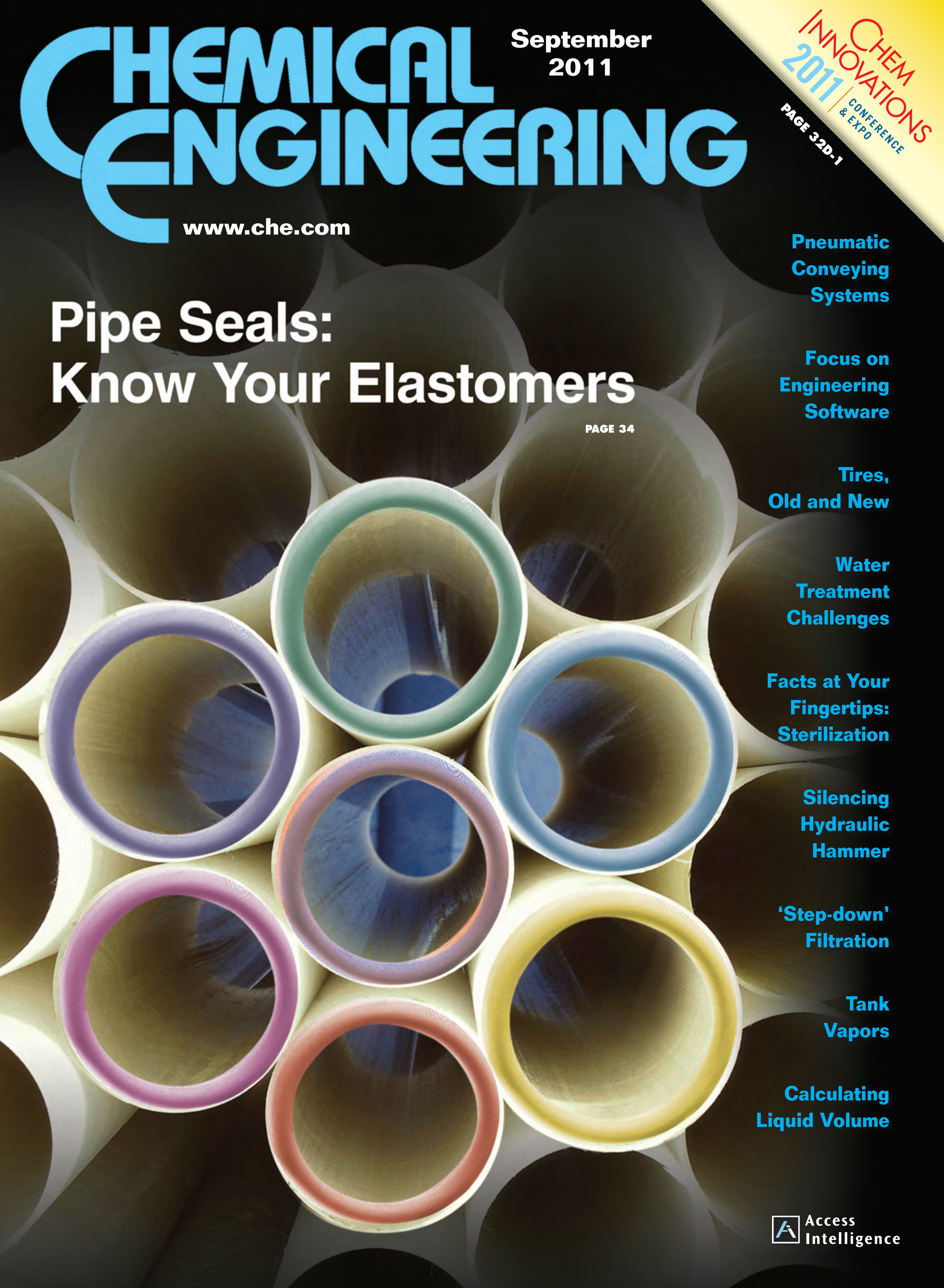

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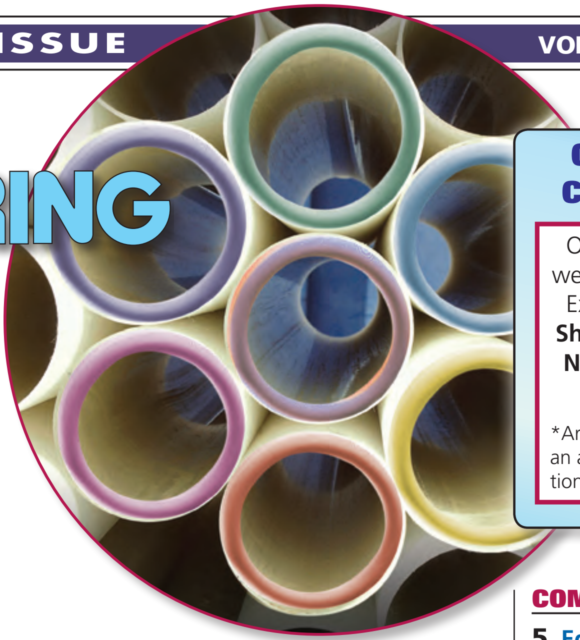

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Editor's Page

Kirkpatrick finalists announced

Four finalists have been selected for the 2011 Kirkpatrick Award for Chemical Engineering Achievement. The winner will be announced Monday, September 12 in Houston at a reception to kick off ChemInnovations. All *CE* readers are invited and may register at www.cpievent.com.

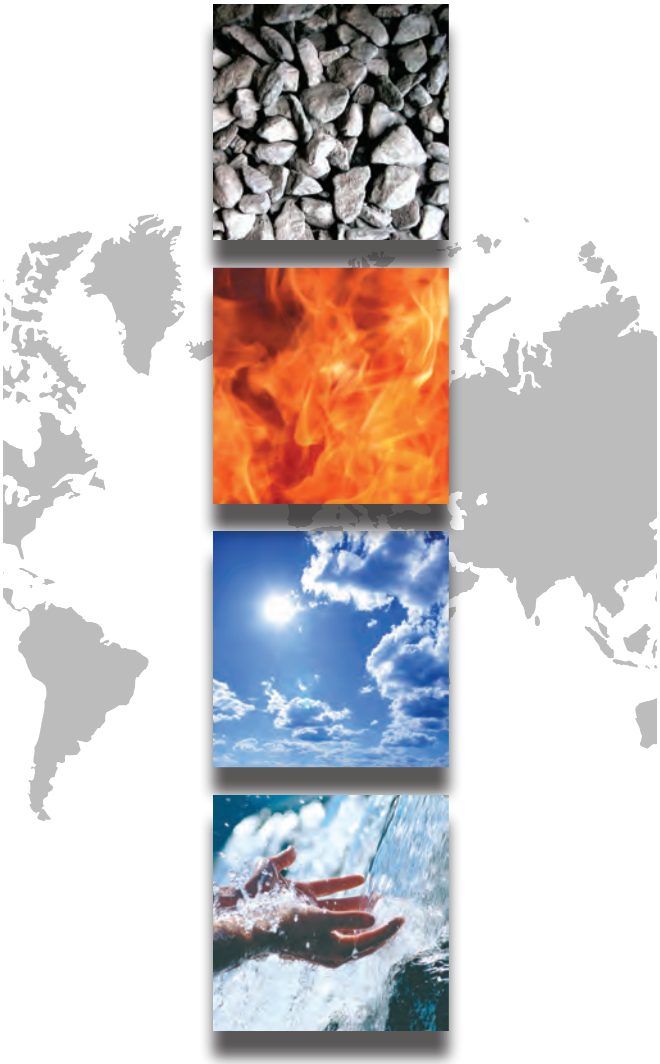
Environ International Corp. — Cost-saving control device for facility-generated volatile organic compound (VOC) emissions: Removal of VOC emissions, especially benzene from petroleum refineries, is tightly regulated by regulatory authorities and has been limited primarily to vapor phase adsorption (activated carbon) and thermal oxidation (incineration). Environ International has developed and received regulatory certification (in the U.S.) for an alternative control device that treats air emissions in an activated-sludge aeration tank — equipment that already exists in most facilities for the purpose of wastewater treatment. The Environ solution removes VOC vapor-phase emissions from the air medium by diffusing them directly into the aqueous-phase activated-sludge system, which is already acclimated to the organic compounds requiring treatment. In comparison to traditional methods, the new process conserves energy by eliminating either fuel for thermal oxidizers or fuel to transport and regenerate spent carbon offsite.

Invensys Operations Management and ConocoPhillips — Advanced alkylation measurement solution. Hydrogen fluoride (HF) alkylation is the most widely used process for synthesis of isooctane (octane) for gasoline blending. In this process, tight control of the constituent concentrations can save millions of dollars per year. Early approaches to HF monitoring involved taking manual samples and analyzing them in a laboratory, which offers limited accuracy and exposes workers to toxins. More recent techniques are very accurate, but adaptation for realtime online monitoring is complex and costly. Invensys and ConocoPhillips have developed a non-spectroscopic measurement solution called ACA.HF Advanced Alkylation that simplifies and dramatically lowers the cost of online monitoring of HF, while reducing risk to plant workers. The system costs about half that of contemporary systems and requires minimal maintenance because its core components are built from rugged materials long proven in industrial HF applications.

NSR Technologies, Inc. — Green route to potassium hydroxide and hydrochloric acid. NSR has commercialized a new chemical pathway for producing 45–50% KOH solution and 7% HCl via membrane separations technology and ion-exchange chromatography. The first environmentally friendly, cost-effective alternative to electrolysis (chlor-alkali) in decades, the NSR process yields high purity products that are free of mercury and oxidizing species, and does not produce the hazardous air pollutant chlorine. NSR's novel multipass design reduces the fluid recirculation requirements, which reduces overall plant size, space requirements and cost. Salt contamination is minimal, and 40% less energy is consumed per unit of product manufactured.

Oxford Catalysts and Velocys — Small-scale, modular synthetic-fuel technology. Velocys has developed facilities for the conversion of associated or stranded gas into synthetic gas-to-liquids (GTL) fuels, as well as biomass- and coal-to-liquids (BTL/CTL), producing synthetic fuels economically from just 5 million standard cubic feet per day of gas, or 500 metric tons per day of biomass or coal. Steam methane reforming (SMR) and Fischer-Tropsch (F-T) reactors accelerate reactions by up to 1,000-fold and intensify processes by minimizing heat- and mass-transport limitations, with safety, efficiency and size benefits. Sister company Oxford Catalysts provides superactive, selective, stable F-T catalysts, optimized for microchannel reactors. ■

Rebekkah Marshall



Letters

Chopey scholarship awarded

The 2011 Nicholas Chopey Scholarship for Chemical Engineering Excellence has been awarded to Eric Fees, a third-year chemical engineering student at the University of Kansas (Lawrence; www.ku.edu). Fees is studying abroad this summer, focusing on energy transport research. He is a member of Tau Beta Pi, National and University of Kansas chapters of AIChE, and the University of Kansas Honors Program. He is also a recipient of the Summerfield Scholarship, College of Engineering Scholarship, and Chemical Engineering Scholarship. Fees is a graduate of Manhattan High School.

About the scholarship

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

For 47 years, Nick carried many torches at *CE,* including those for its Kirkpatrick and Personal Achievement Award competitions that are held in alternating years. Meanwhile, he was a recognized authority on the chemical process industries (CPI) and a champion of the practical, how-to literature upon which outstanding CPI achievement finds foundation. He was a mentor to many chemical engineers, young and old.

To honor and continue Nick's valuable and lasting contributions to the chemical engineering profession, *Chemical Engineering* established the scholarship in his name and accepts donations annually.

Details and qualifications for applicants. The scholarship is a one-time award for current third-year students who are enrolled in a fulltime undergraduate course of study in chemical engineering at one of the following four-year colleges or universities, which include Mr. Chopey's alma mater and those of our senior editorial staff:

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

The program utilizes standard Scholarship America recipient-selection procedures, including the consideration of past academic performance and future potential, leadership and participation in school and community activities, work experience, and statement of career and educational aspirations and goals.

Donations. To donate to next year's scholarship fund, please send a check to the following address prior to June 1, 2012:

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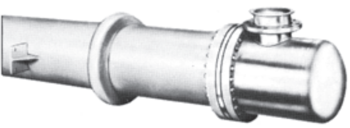

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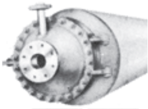

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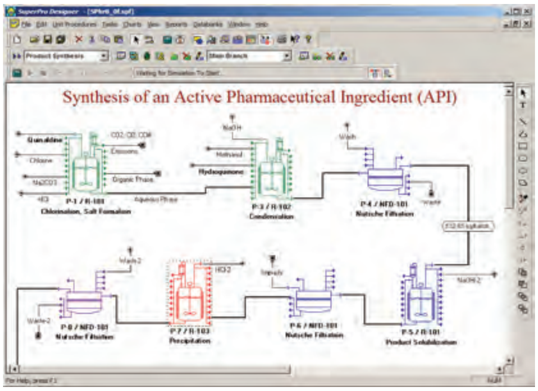

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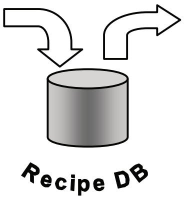

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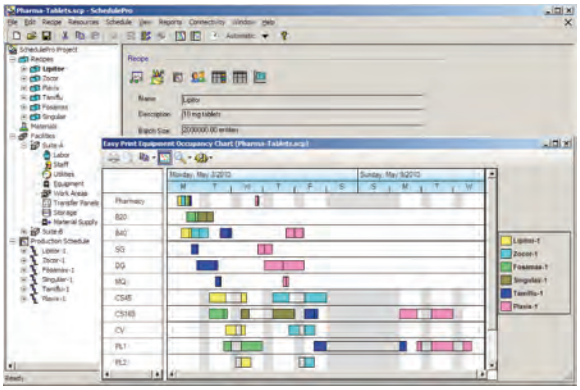

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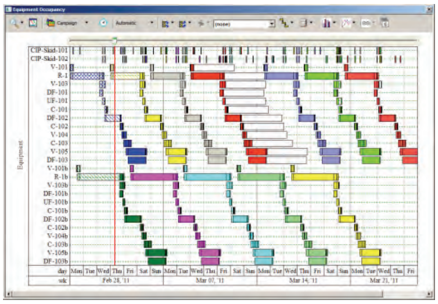

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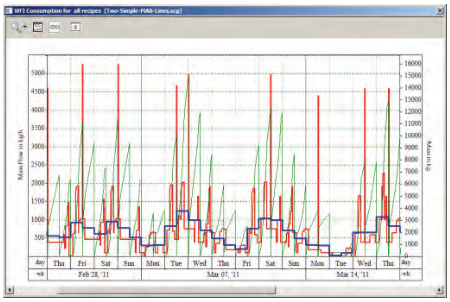

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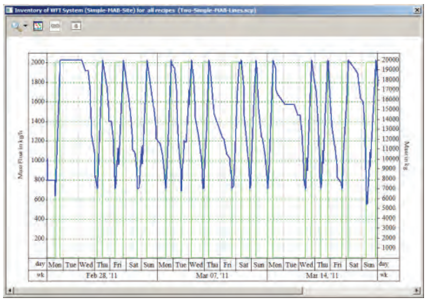

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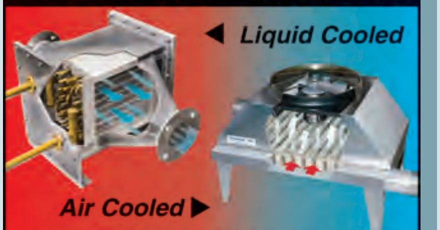

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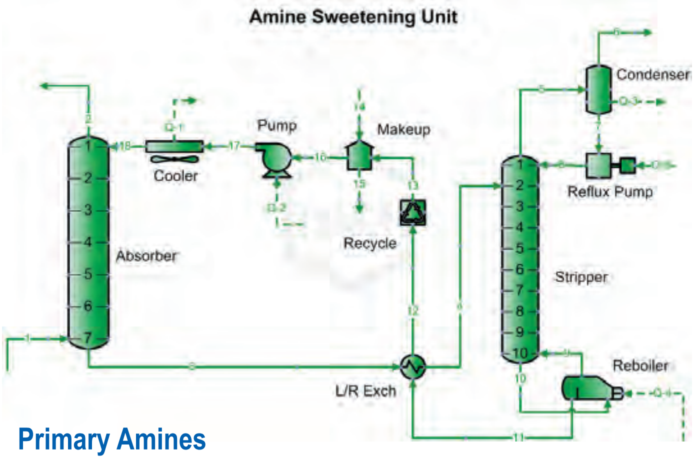
PROCESS INSIGHT

Selecting the Best Solvent for Gas Treating

Selecting the best amine/solvent for gas treating is not a trivial task. There are a number of amines available to remove contaminants such as CO_2, H_2S and organic sulfur compounds from sour gas streams. The most commonly used amines are methanolamine (MEA), diethanolamine (DEA), and methyldiethanolamine (MDEA). Other amines include diglycolamine® (DGA), diisopropanolamine (DIPA), and triethanolamine (TEA). Mixtures of amines can also be used to customize or optimize the acid gas recovery. Temperature, pressure, sour gas composition, and purity requirements for the treated gas must all be considered when choosing the most appropriate amine for a given application.



Primary Amines

The primary amine MEA removes both CO_2 and H_2S from sour gas and is effective at low pressure. Depending on the conditions, MEA can remove H_2S to less than 4 ppmv while removing CO_2 to less than 100 ppmv. MEA systems generally require a reclaimer to remove degraded products from circulation. Typical solution strength ranges from 10 to 20 weight % with a maximum rich loading of 0.35 mole acid gas/mole MEA. DGA® is another primary amine that removes CO_2, H_2S, COS, and mercaptans. Typical solution strengths are 50-60 weight %, which result in lower circulation rates and less energy required for stripping as compared with MEA. DGA also requires reclaiming to remove the degradation products.

Secondary Amines

The secondary amine DEA removes both CO_2 and H_2S but generally requires higher pressure than MEA to meet overhead specifications. Because DEA is a weaker amine than MEA, it requires less energy for stripping. Typical solution strength ranges from 25 to 35 weight % with a maximum rich loading of 0.35 mole/mole. DIPA is a secondary amine that exhibits some selectivity for H_2S although it is not as pronounced as for tertiary amines. DIPA also removes COS. Solutions are low in corrosion and require relatively low energy for regeneration. The most common applications for DIPA are in the ADIP® and SULFINOL® processes.

Tertiary Amines

A tertiary amine such as MDEA is often used to selectively remove H_2S, especially for cases with a high CO_2 to H_2S ratio in the sour gas. One benefit of selective absorption of H_2S is a Claus feed rich in H_2S. MDEA can remove H_2S to 4 ppm while maintaining 2% or less CO_2 in the treated gas using relatively less energy for regeneration than that for DEA. Higher weight percent amine and less CO_2 absorbed results in lower circulation rates as well. Typical solution strengths are 40-50 weight % with a maximum rich loading of 0.55 mole/mole. Because MDEA is not prone to degradation, corrosion is low and a reclaimer is unnecessary. Operating pressure can range from atmospheric, typical of tail gas treating units, to over 1,000 psia.

Mixed Solvents

In certain situations, the solvent can be “customized” to optimize the sweetening process. For example, adding a primary or secondary amine to MDEA can increase the rate of CO_2 absorption without compromising the advantages of MDEA. Another less obvious application is adding MDEA to an existing DEA unit to increase the effective weight % amine to absorb more acid gas without increasing circulation rate or reboiler duty. Many plants utilize a mixture of amine with physical solvents. SULFINOL is a licensed product from Shell Oil Products that combines an amine with a physical solvent. Advantages of this solvent are increased mercaptan pickup, lower regeneration energy, and selectivity to H_2S.

Choosing the Best Alternative

Given the wide variety of gas treating options, a process simulator that can accurately predict sweetening results is a necessity when attempting to determine the best option. ProMax® has been proven to accurately predict results for numerous process schemes. Additionally, ProMax can utilize a scenario tool to perform feasibility studies. The scenario tool may be used to systematically vary selected parameters in an effort to determine the optimum operating conditions and the appropriate solvent. These studies can determine rich loading, reboiler duty, acid gas content of the sweet gas, amine losses, required circulation rate, type of amine or physical solvent, weight percent of amine, and other parameters. ProMax can model virtually any flow process or configuration including multiple columns, liquid hydrocarbon treating, and split flow processes. In addition, ProMax can accurately model caustic treating applications as well as physical solvent sweetening with solvents such as Coastal AGR®, methanol, and NMP. For more information about ProMax and its ability to determine the appropriate solvent for a given set of conditions, contact Bryan Research & Engineering.

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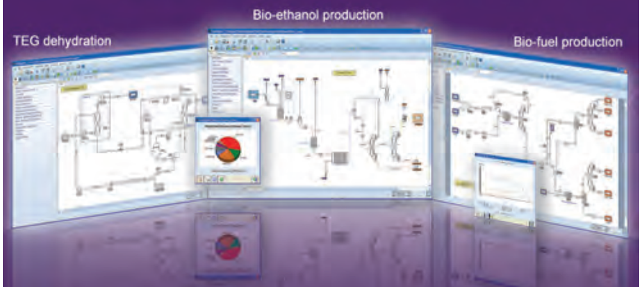
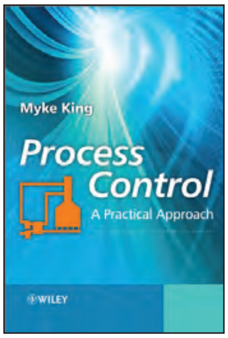


Bookshelf



Process Control: A Practical Approach. By Myke King. John Wiley & Sons Inc., 111 River Street, Hoboken, NJ 07030. Web: xlibris.com. 2008. 196 pages. $50.99.

Reviewed by Ronnie Montgomery,
Kvaerner America,
Houston

Those of us who have been challenged by the complexities of process-control-loop strategies can appreciate the in-depth knowledge and experience that Myke King has shared with us in this text.

This book provides an excellent guideline for engineers and technicians who are responsible for selecting the monitoring and control devices that are typical for most process applications. Further details are given for the initial tuning parameters for a variety of loop arrangements.

Experience has shown that it is very difficult to precisely predict how a given process will react once the hardware and software are in place and configured. In most cases, the practice of trial and error, followed by finetuning during commissioning, continues to be the most common approach. However, following the suggestions presented in this textbook will very likely save valuable time during startup, and may enhance the overall process efficiency to some degree.

The book clearly explains common process-control terminology, and the reader is taken along a path from simple proportional and integral (PI) and proportional, integral and derivative (PID) control loops to the most complex loops imaginable. Those individuals responsible for programming and configuring process-control loops for a distributed control system (DCS) or programmable logic controller (PLC) will benefit from the abundance of formulas and control illustrations.

The book closes with a set of chapters dedicated to specific processes, such as process controls for fired heaters and compressors. The book also provides comprehensive coverage for distillation control.

This book can be considered a valuable reference for process-control systems engineers, process engineers and mechanical engineers. It may be possible for readers to become overwhelmed by the volume of mathematical equations, graphs and process illustrations contained in the book, but the knowledge and experiences with which the author uses such details as the basis for his control strategies is to be appreciated. I intend to keep this book in my library as a handy reference for any new project that comes along.

Update on Troubleshooting the PVC Extrusion Process. By Natami Subramanian Muranisrinivasan. iSmithers Rapra Publishing, Shawbury, Shrewsbury, Shropshire, SY4 4NR, U.K. Web: polymer-books.com. 2011. 164 pages. $130.00.

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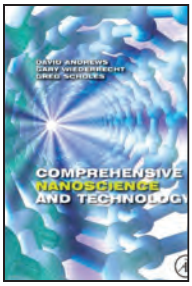

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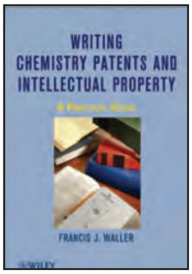

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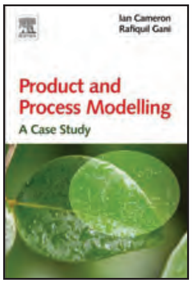
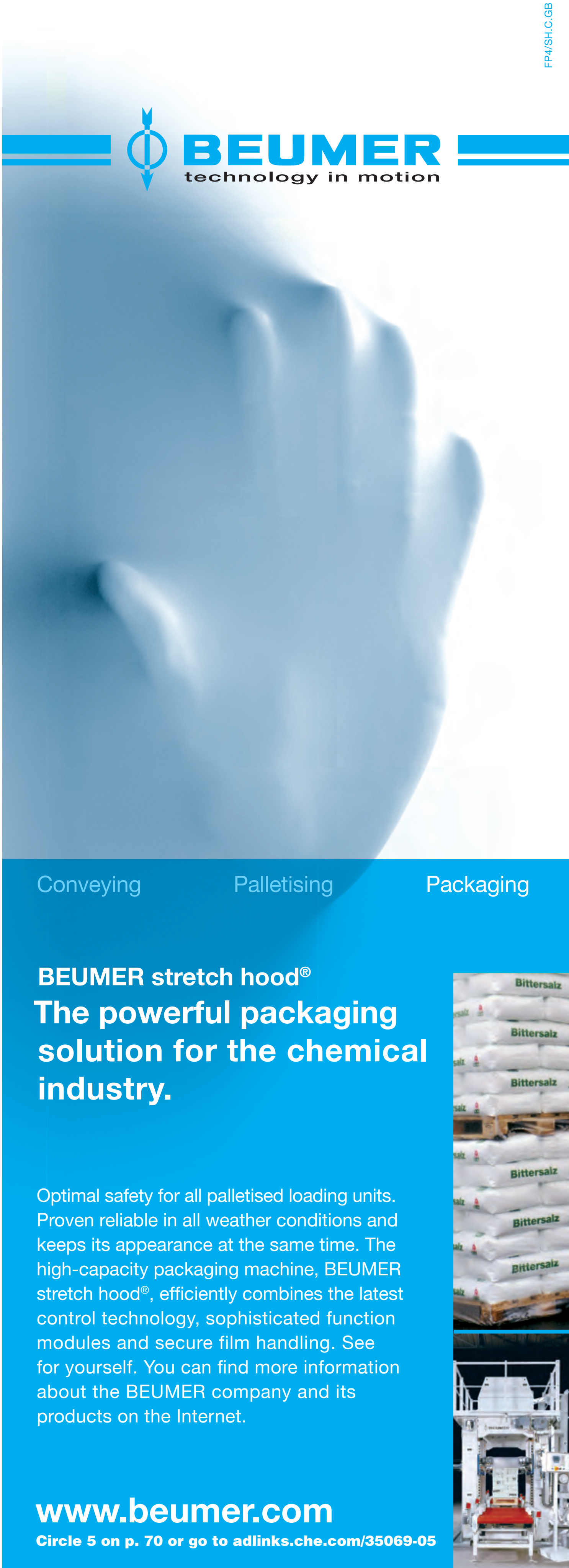
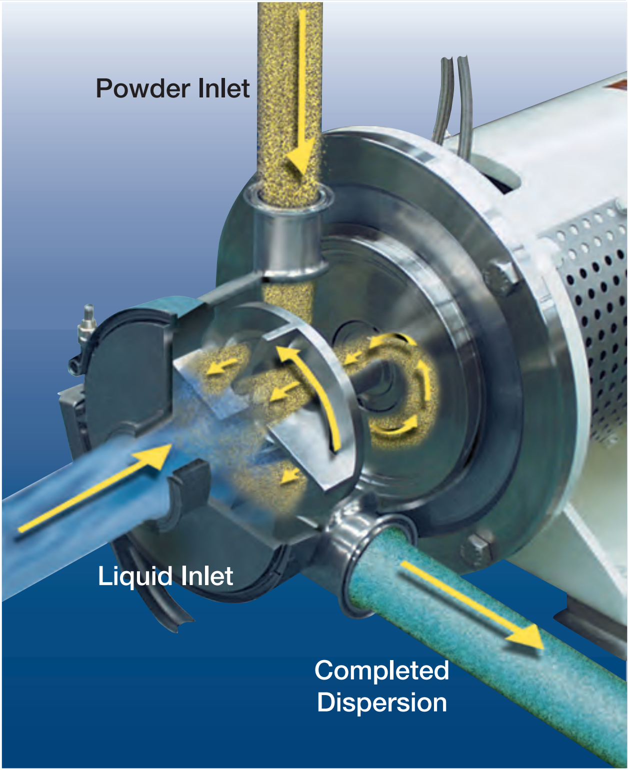


Product and Process Modelling: A Case Study Approach. By Ian T. Cameron and Rafiqul Gani. Elsevier Inc., 30 Corporate Drive, 4th Floor, Burlington, MA 01803. Web: elsevier.com. 2011. 548 pages. $119.00. ■

Scott Jenkins

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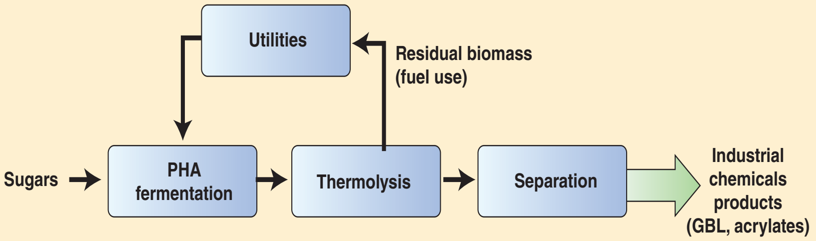
CHEMENTATOR

Edited by Gerald Ondrey September 2011

Microbe-based process for GBL nears commercialization



Metabolix Inc. (Cambridge, Mass.; www.metabolix.com) has successfully demonstrated and completed research and development for scaleup on a fermentation process that produces *gamma*-butyrolactone (GBL) from genetically engineered bacteria.

The process is built upon the company's technology for engineering metabolic pathways into microbes that produce specific biopolymers. "We've been able to control microbe biology such that high concentrations of specific, naturally occurring biopolymers accumulate in the cells as they metabolize sugars," explains Oliver Peoples, Metabolix co-founder and chief scientific officer.

Further, Metabolix has refined and applied a process known as fast-acting, selective thermolysis (FAST process) that converts biopolymers, such as, in this case, poly-4-hydroxybutyrate (P4HB), into GBL, a chemical intermediate and solvent used in a variety of industrial applications.

In a fermentation step, Metabolix's engineered microorganisms accumulate biopolymer precursors — "80% of the dry weight of the cells is P4HB," remarks Johan van Walsem, the company's vice president of strategy and commercial development. In the FAST process, the whole fermentation broth is dried and then heated under specific conditions where the thermally labile P4HB molecules decompose into GBL. By starting with microbes engineered to metabolize sugars into a specific biopolymer, and by controlling the conditions of the thermodynamically driven decomposition, the FAST process is able to selectively produce desired products in high yields and with high purities.

The Metabolix process has significant advantages, including its ability to recover 90–95% pure product in a single recovery step. Also, the residual biomass from the fermentation step is converted to char and combusted for process heat, making the FAST process energetically self-sustaining. Finally, the water from the fermentation broth is recycled after the product is isolated, eliminating wastewater.

GBL is the product that is furthest along in the path to commercialization, but Metabolix is progressing toward commercializing other bio-based chemicals, including acrylic acid, using a similar process. Engineering for a full-scale GBL plant will be ready to begin by 2011's end.

'Green' surfactants from yeast

A new yeast strain that could one day substitute for petroleum as a source of surfactants for detergents, soaps and cosmetics has been identified by researchers at the U.S. Dept. of Agriculture's National Center for Agricultural Utilization Research (Peoria, Ill.; ars.usda.gov). The yeast, not yet named, is a member of the *Candida* genus of yeasts and produces sophorolipids (a sugar-based biodetergent), says microbiologist Cletus Kurtzman, head of the research team. The benefits, he says, are that the sophorolipids are renewable and biodegradable.

Kurtzman notes that sophorolipids are also produced by other *Candida* yeasts, such as *C. bombolica* and *C. apicola*, and their products are made commercially by two companies in the world for use in cosmetics and hand-washing soap. However, these yeasts produce sophorolipids that have closed-chain molecules, whereas the product of the newly discovered strain has open-chain molecules, which have a lower critical micelle concentration, says Neil Price, a research chemist. All sophorolipids are low-foaming, he explains, but the open-chain structure forms micelles more efficiently.

The new yeast, cultured in a mixture of glucose and oleic acid, produces 20 g/L of sophorolipids, but the researchers say the yield could be increased tenfold by optimizing the process (for example, increasing the oxygen flow and the amount of substrate). The group is seeking an industrial partner to scale up the process and to test the sophorolipids in products and applications.

Phosgenation scaleup

At the end of July, Bayer MaterialScience AG (BMS; Leverkusen, Germany; www.bayerbms.com) successfully tested its new gas-phase phosgenation technology at a new plant being commissioned for making toluene diisocyanate (TDI) — a raw material for making polyurethane — at its integrated production site at Caojing in Shanghai, China. The TDI facility is expected to come onstream, stepwise, later this year, building to its full capacity of 250,000 metric tons (m.t.) per year.

The phosgenation process, which was implemented together with Bayer Technology Services GmbH (Leverkusen, Germany; www.bayertechnology.com), is said to reduce solvent consumption by around 80% for a plant this size, and cut energy consumption by up to 60%, compared to conventional liquid-phase processes. Compared to conventional production facilities of similar size, the gas-phase process also cuts CO_2 emissions by around 60,000 m.t./yr. The new process also lowers investment costs by about 20%, says BMS (for more process details, see *CE*, May 2007, p. 17).

A new catalyst site

A new catalytic site of oxidation catalysts has been identified by scientists at the University of Virginia's (Charlottesville; www.virginia.edu) chemistry and chemical engineering departments. Using

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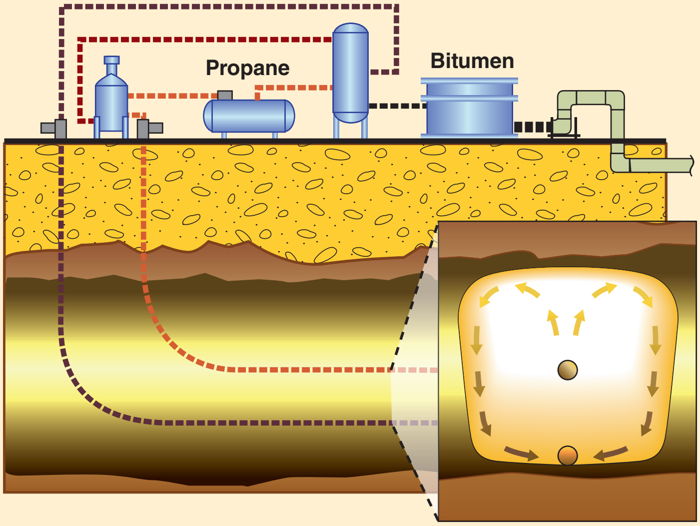
Note: For more information, circle the 3-digit number on p. 70, or use the website designation.

Solvent extraction method shows promise for recovering bitumen from tar sands



Today only a few percent of Canada's oil sands resource is accessible by traditional surface mining, so the rest has to be recovered in situ, mostly by steam-assisted gravity drainage (SAGD). In this process, steam is injected into a horizontal well in the oil formation to mobilize the viscous bitumen, which is recovered by a producer well at a lower level. An in-situ process that promises to be more efficient and less expensive is being developed by N-Solv Corp. (Calgary, Alta.; www.n-solv.com) and will be field-tested in a 300-bbl/d pilot plant north of Fort McMurray, starting in the first half of 2013.

The basic configuration of N-Solv's method is similar to that of SAGD, except that propane (or some other solvent) is used, rather than steam. Propane vapor is injected into the formation at about 40°C and 200 psi, compared with approximately 230°C and 300–400 psi for steam, says N-Solv president John Nenniger. The solvent condenses on the cold walls of the vapor chamber and dissolves the bitumen, which drains with the solvent down to a production well. The vapor chamber gradually expands as the bitumen interface is removed. A surface facility separates the propane and non-condensable gases (mostly methane) from the bitumen, then the propane is recovered by distillation and recycled.

In laboratory-scale tests, the process has achieved oil extraction rates comparable to those of SAGD, says Nenniger. A significant advantage, he adds, is that the solvent selectively dissolves the valuable, lower-gravity components of the bitumen, leaving behind most of the sulfur and heavy metals in an asphaltene residue. In SAGD, these unwanted components are mobilized, then rejected by an upgrader as waste coke. Consequently, N-Solv oil is about 25% more valuable than SAGD-produced bitumen, he says. The capital cost is expected to be half that of a comparable steam facility.

Boost heavy metal recovery from wastewater with graphite-oxide coated sand

A process to greatly enhance the ability of sand to filter heavy metals from water has been developed by researchers from Monash University, of Melbourne, Australia (www.monash.edu.au), Rice University (Houston; www.rice.edu) and Nanoholdings LLC (Marietta, Ga.; www.nanoholdings.com). Historically, the researchers say, water purification has utilized high-surface-area carbon materials in the form of activated carbon for decolorization and heavy-metal ion retention. On the other hand, several methods have been proposed to utilize graphite oxide (GO) as a material for low-cost water purification. However, those methods reduce the ability of GO to sequester water-soluble contaminants, such as heavy metals.

The researchers claim that, by suitable surface modification and subsequent assembly steps, they produced GO that adsorbs six-fold higher concentration of aqueous mercury ions than the unmodified GO. A simple technique was developed for converting regular filtration sand into "core-shell" GO-coated sand granules. The GO coating imparts nanostructural features on the surface of the sand granules, which can significantly increase the retention of heavy metals and organic dye over the parent sand granules.

The assembly process consists of physical mixing of water-dispersible GO colloids with sand, followed by a mild treatment that causes the nanosheets to adhere to each other over the sand surface, probably through van der Waals interaction.

The researchers applied a surface modification technique to synthesize hydrophilic GO nanosheets containing covalently attached thiol groups. The modification is achieved through carbon-carbon attachment of benzene-thiol groups to the sp^2 lattice within the nanosheets. The GO nanosheets retain electron-rich sp^2 domains that can be used for grafting additional complexing groups.

(Continued from p. 11)

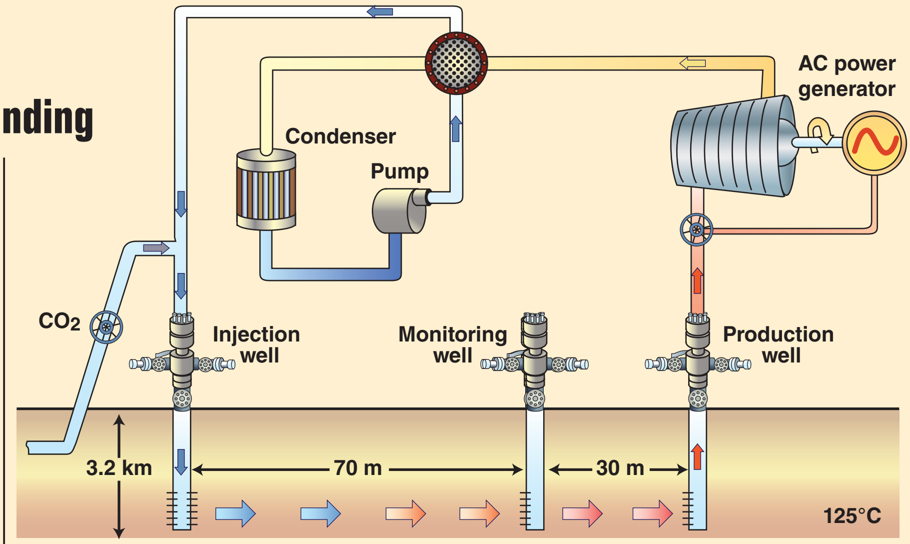
a titanium-dioxide substrate supporting nanometer-sized gold particles, the researchers found a site at the perimeter of the Au and TiO_2; there, an oxygen molecule is bonded to a gold atom and to an adjacent Ti atom. Neither the gold nor the TiO_2 exhibit the observed catalytic activity when studied alone, says chemistry professor John Yates.

'Canary' for water plants

Public water systems can now be better protected from terrorist attack and contaminants thanks to Canary Event Detection Software — an open-source software developed by Sandia National Laboratories (Albuquerque, N.M.; www.sandia.gov) in partnership with the U.S. Environmental Protection Agency (EPA; Washington, D.C.; www.epa.gov). The free software tells utility operators, within minutes, whether something is wrong with their water, giving them time to

(Continues on p. 14)

Carbon storage and electricity generation project gets DoE funding



A project aimed at using geothermal heat to power an electricity-producing turbine with supercritical carbon dioxide has received a \$5 million grant from the U.S. Dept. of Energy (DOE; Washington, D.C.; www.energy.gov). The project also incorporates an element of CO_2 sequestration in sedimentary rock, whereby a portion of the CO_2 injected into the hot sedimentary layer remains there, so that the process requires a constant stream of CO_2.

The three-year project, led by researchers at Lawrence Berkeley National Laboratory (Berkeley, Calif.; www.lbl.gov), represents the first attempt to convert geothermally heated CO_2 into useful electricity. "The project is focused on validating the concept of using CO_2 as a working fluid in the subsurface for geothermal energy production," says Berkeley Laboratory researcher Barry Freifeld.

The process would begin by injecting CO_2 into a wellbore at a supercritical state (pressure above 70 bars and temperature greater than 31°C) into a layer of 125°C sedimentary rock that lies over 3 km beneath the earth's surface. Under these conditions, CO_2 becomes more pressurized and further heated in the underground rock. The higher-pressure, higher-temperature CO_2 is extracted through a separate but nearby producer well. It is expanded through a heat-engine turbine, where its higher enthalpy is converted to shaft work. The turbine generates electricity, and the CO_2 is cycled through the loop again. The geothermal-heat system will be designed so that a portion of the CO_2 remains stored in the rock, and a continuous supply of new CO_2 will be supplied to the loop.

The turbines, to be designed and built by Echogen Power Systems (Akron, Ohio; www.echogen.com), will be based on technology already developed by the company — a supercritical CO_2-based power-generation system for low-temperature waste heat recovery that has a turbine similar to that required by the geothermal project.

Pilot testing is planned for the third year of the project at the Cranfield site in Mississippi, where a DOE injector well and two heavily instrumented monitor wells for carbon sequestration research already exist.

Plastics-to-oil JV plans full-scale facility

A joint venture (JV) between Vadxx Energy LLC (Akron, Ohio; www.vadxx.com) and Greenstar Recycling (Houston; www.greenstarrecycling.com) plans to start up a facility in mid-2012 to convert recovered plastics to synthetic crude oil. When complete, the facility will produce 80,000 bbl/yr of synthetic crude oil from 12,000 ton/yr of solid municipal plastics.

Using a thermal depolymerization process, the JV intends to produce low-sulfur synthetic crude oil from a wide range of post-consumer plastics for which a robust recycling market does not yet exist. Vadxx chief operating officer Sean Arnold says his company's synthetic crude oil is designed to meet various specifications for specific gravity, sulfur content and other properties sought by petroleum refiners.

Building on work begun by researchers at the University of Wyoming, Vadxx has been refining its process at its Akron, Ohio pilot plant for the past two years, after years of preliminary research carried out by Vadxx chief technology officer Bill Ullom. As feedstock, the process can use an unsorted mixture of plastics, most likely those with recycling code numbers 2–7, such as high-density polyethylene, low-density polyethylene, polypropylene, polystyrene and polycarbonate.

While the Vadxx thermal depolymerization process does not exploit novel chemical pathways, careful control of the process details is key to effectively and efficiently converting the plastics to crude. "In principle, the plastics-to-oil process just reverses the path used to produce plastics from oil, but the challenge has been to work out the fine details of the process to allow it to operate at low energy," explains Arnold.

(Continued from p. 13)

warn and protect the public. It is already being used in Cincinnati, Ohio and Singapore, and is also being tested in Philadelphia, Pa.

Canary runs on a desktop computer, and can be customized for each utility to work with existing sensors and software. One key to the software is its ability to reduce the number of false alarms. This is done using a specially designed numerical algorithm to analyze data coming from multiple sensors, and differentiate between natural variability and unusual patterns that indicate a problem. Canary also provides information about gradual changes in the water.

Ethanol-to-isobutene

Scientists at the Pacific Northwest National Laboratory (Richland, Wash: www.pnnl.gov) and Washington State University (Pullman, Wash.; www.wsu.edu) have discovered a new catalyst that converts ethanol into isobutene in a single step, with 83% conversion. The catalyst — a mixed metal oxide of zirconium and zinc — was initially being developed to convert ethanol into hydrogen, when postdoctoral researcher Junming Sun observed not only H_2, but quite a bit of isobutanol — a precursor for making rubber.

A simpler process to make PX from LCO

A new process to make BTX (benzene, toluene and xylenes) from light cycle oil (LCO), an oversupplied product of petroleum refineries that can supplement the dwindling supply of BTX precursors, is being developed by JX Nippon Oil & Energy (JX Energy; Tokyo, Japan; www.noe.jx-group.co.jp). Whereas conventional technology requires multiple reactors and large quantities of hydrogen to make aromatic compounds from LCO, JX Energy's process takes place in a single reactor. The company has prepared laboratory quantities of a new catalyst that is said to deliver higher yields of BTX than alternatives, with high yields for *para*-xylene (PX).

By the end of this year, JX Energy plans to build a bench-scale production plant at its Central Research Laboratory in Kanagawa Prefecture, in collaboration with Chiyoda Corp. (Tokyo; www.chiyoda-corp.com), and financial support from the Japanese Petroleum Energy Center (JPEC) under the authority of Ministry of Economy, Trade and Industry (METI).

JX Energy already supplies 2,600,000 ton/yr of PX, but is hindered by the reduction of crude-oil treatment caused by the gradual decrease of domestic demand for petroleum products. The company anticipates that its LCO-based process will ensure a stable supply of PX in the future.

Biomass pretreatment

Cellulosic biomass pretreated with ammonia undergoes structural changes that make it more susceptible to enzymatic attack, scientists at Los Alamos National Laboratory (Los Alamos, N.M.; www.lanl.gov) and collaborators at the Great Lakes Bioenergy Research Center (Madison, Wisc.; www.glbrc.org) have found. Combining advanced molecular modeling with experimental data, the team observed a weakening of the hydrogen-bond network that holds bulk cellulose together in a highly ordered stack. The tightly bound network of cellulose prevents enzymes from attacking most of the individual cellulose molecules to produce sugar. The discovery could lead to a less costly and less toxic pretreatment regime for making biofuels from cellulosic biomass. The current pretreatment method involves costly and harsh chemicals in an energy-intensive process.

Monomers from glucose

Mitsubishi Chemical Corp. (MCC; Tokyo, www.m-kagaku.co.jp, MCC) is developing bio-based technology for producing propylene, butadiene, 1,4-butanediol (BDO), terephthalic acid and succinic acid from glucose. In collaboration with North American partners, MCC plans to start production of succinic acid and 1,4 BDO. MCC says it will be able to produce butadiene for less than $2,000/kg — about half the current price. The bacteria-based technology for directly producing monomers from sugar has the advantage over other fermentation routes because it does not first go through ethanol production, says MCC.

A promising method for producing conductive graphene sheets

Since the isolation of graphene by the "Scotch tape" method, many researchers have tried to synthesize solution-dispersible graphene. The challenge has been to develop a high-yield method that can exfoliate graphite efficiently into solution-dispersible graphene sheets without collateral damage to the graphene due to oxidation, or due to the use of a strong acid. A nonoxidative electrochemical process to obtain few-layer, highly conductive graphene flakes with a yield higher than 70% has been developed by a team from the Dept. of Chemistry, National University of Singapore (www.nus.edu.sg). The team says the yield they obtained is significantly higher than that produced by most current liquid-phase exfoliation methods. This is important for the scalable synthesis and industrial application of graphene.

The team's exfoliation method was inspired by the electrochemical reactions of negative graphite electrodes in liquid-rechargeable lithium ion batteries. During electrochemical charging in a graphite electrode, Li^+ ions are reversibly intercalated into the graphite layers. A promising solvent for lithium ion batteries is propylene carbonate (PC). However, its use is limited because of its destructive behavior toward the graphite cathode.

The team discovered that this destructive behavior of the Li/PC complexes can be exploited for the high-yield exfoliation of graphite to produce few-layer graphene flakes.

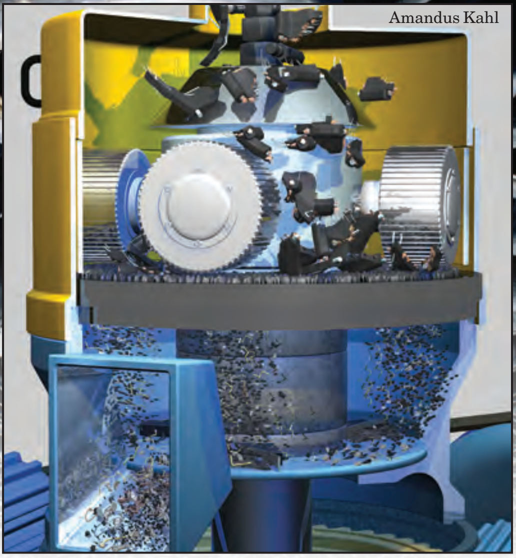
Unlike the low voltage (typically less than 1 V) and low-current electrochemical charging conditions typically used in graphite intercalation compounds, the team applied a high voltage (10–20 V) in order to activate Li/PC intercalation in graphite. The application of a high charging voltage aids the expansion of the electrode by Li-PC complexes. Using high-intensity ultrasound, the team sonicated the expanded graphite in concentrated LiCl dissolved in PC and N,N-dimethylformamide. Ultrasonic cavitation results in both exfoliation and cutting of the graphite sheets. The dispersible graphene can be ink-brushed to form highly conformal coatings of conductive films on commercial paper. ■

New Cl_2 process starts up

Last month, Bayer MaterialScience started up a 20,000-m.t./yr chlorine demonstration plant at the Chempark Krefeld-Uerdingen, Germany site. The plant uses the oxygen-depolarized cathode technology, developed together with Uhde GmbH (Dortmund, Germany) and UhdeNora S.p.A. (Milan, Italy), which significantly reduces the energy demand for producing Cl_2. Assuming the two-year trial demonstration is sucessful, Bayer plans to gradually switch its Cl_2 production to the new process (for more details about the process, see *CE*, May 2007, pp. 50–55 and March 2004, p. 17). ❑

TIRES, OLD AND NEW

As the demand for new, fuel-efficient tires grows, engineers are developing new recycling methods to deal with the growing piles of used tires



Amandus Kahl

FIGURE 1. Mechanical methods have been the main way to recycle tires. This new grinding technology produces better quality steel and rubber crumb, while consuming less energy than traditional methods

Mobility as a "megatrend" has recently become the latest buzz-word, and synthetic rubber producers are boosting production capacities to meet the anticipated demand for more tires. At the same time, high fuel prices and increasing concern for the environment are driving innovations in rubber to make tires more fuel-efficient (see box on p. 19).

Meanwhile, efforts to find more efficient ways to recycle used tires are progressing, with some companies looking to capitalize on the resources — both energy and materials — that are tightly bound inside discarded tires.

Megatrend mobility

An estimated 5% of the nearly 3-billion Asian population own cars, compared to more than half the 406-million population of Western Europe and 80% of the 306 million in the U.S. So it's not surprising that all of the major tire manufacturers are investing in production plants in China, Thailand, India and elsewhere, to capitalize on the emerging markets there. In May, for example, Continental AG (Hanover, Germany; www.conti-online.com) officially opened its first tire plant in China. The €185-million investment in Hefei, in the Anhui province, has an annual production capacity of 4-million tires, and further expansion at the site to 16 million tires is planned.

Rubber producers, too, are looking east in order to meet the growing demand from tire manufacturers. In May, for example, Lanxess AG (Leverkusen, Germany; www.lanxess.com) broke ground for a new production facility in Singapore. The new plant, which is being built on the man-made Island of Jurong, will have a production capacity of 100,000 ton/yr of butyl rubber. The €400-million investment is the largest investment project in the history of Lanxess. The butyl rubber produced in Singapore will be used primarily in tires. The butyl rubber market is expected to grow steadily over the next 15 years, says Lanxess.

Since tires eventually wear out and have to be discarded, one has to wonder what is going to happen to all the new tires. Already, all over the world, there are mountains of used tires piled up (if readers haven't seen such tire heaps themselves, just type "used tires" into Google Images). Such landfilling is becoming a thing of the past, and today, there are a number of ways to recycle tires.

Recycling today

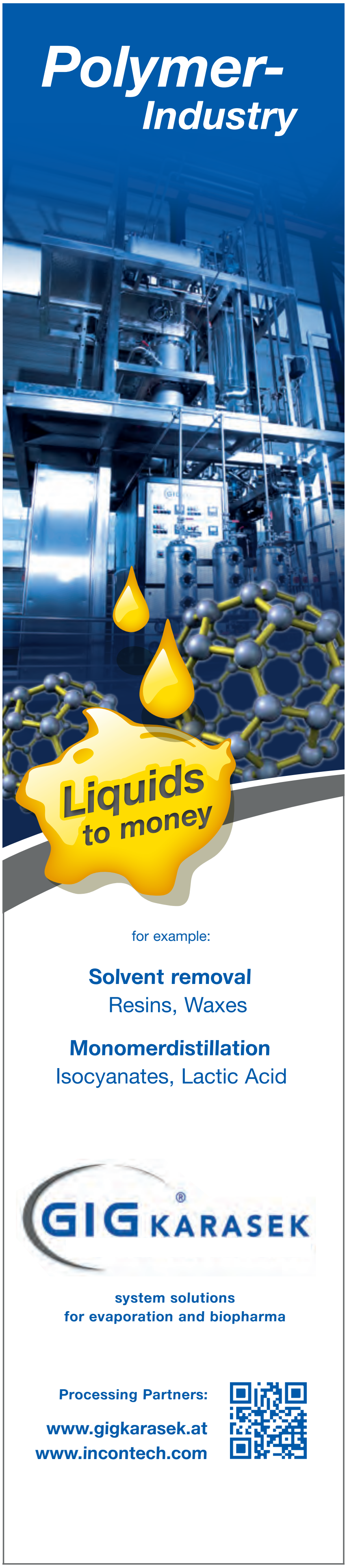
Worldwide, nearly 1-billion tires are manufactured each year, and nearly an equal amount of tires are removed from vehicles and defined as waste, according to the European Tyre Recycling Assn. (ETRA; Brussels, Belgium; www.etra-eu.org). In the E.U. alone, some 3.5-million metric tons (m.t.) of tires become waste each year. Although tires are not the biggest waste stream — over ten times more plastic waste is generated in the E.U. each year — tires contain a number of components that can be recovered for reuse, so recycling can make economical sense. Production of 1 kg of recycled tire granulate consumes 2,200 Btu, while the production of virgin rubber materials consumes more than 120,000 Btu for the same quality, says ETRA.

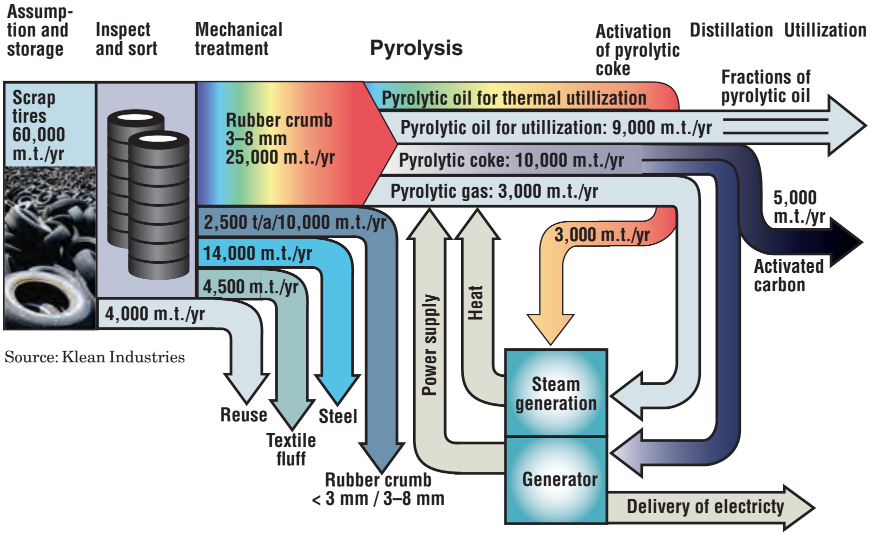
A typical tire is about 45–48 wt.% rubber (both natural and synthetic), 22 wt.% carbon black and silica, 15–25 wt.% metal, as well as textiles, zinc oxide, sulfur and additives. The challenge for recyclers is that the same properties that make tires durable and safe also make it difficult to recover the components in usable form.

What happens to these used tires varies widely by country. In Japan, for example, about 62 wt.% of the used tires in 2010 were used as an alternative fuel in various industries, such as paper manufacturing (39%), cement calcining (10%), steel manufacturing (3%) and others, according to the The Japan Automobile Tyre Manufacturers Association, Inc. (Tokyo; www.jatma.or.jp). Only 10% of the tires were recycled for reclaimed and powdered rubber.

In the U.S., about 76% of the 300-million tires generated annually are recycled, with tire derived fuel (TDF) accounting for about half in 2010, according to Dick Guss, environmental advisory council of the Tire Industry Assn. (Bowie, Md.; www.tireindustry.org).

In the EU, where landfilling of post-consumer tires was banned in 2003 (for shred and recycle residue in 2006), material recycling using a variety of treatments and technologies has grown to more than 36% of post-consumer tires, says ETRA.





Source: Klean Industries

FIGURE 2. Pryolysis is emerging as a more efficient way to utilize the resources in tires compared to simple combustion as an alternative fuel source

Mechanical recycling

The standard way to recycle tires has been by mechanical methods, such as grinding, cutting and shredding, which physically separate out the main components as steel and rubber crumb. Although well established in the scrap industry, mechanical methods are continuously being improved to reduce costs and improve the quality of the recovered products.

For example, Amandus Kahl GmbH, (Reinbek, Germany; www.amandus-kahl-group.de) recently introduced its ambient-grinding process that is said to be more economical than traditional ambient or cold grinding processes. The process features the company's granulation press (Figure 1), in which tire chips (50–100-mm size) are ground between cylindrical pan-grinder rollers and a circular die designed as a perforated plate. The shearing force produced by the pan grinder, as well as the pressing force (up to 120 bar) applied by a regulated hydraulic system, decompose the tire parts and separate the components.

A Type 60-1250 granulation press processes up to 4.5 ton/h of tire chip to a granular size of 0.4–20 mm, which can then be classified into different product grades. A typical separation result is 15–20% steel, 15–20% textile-rubber mixture, and rubber crumb (4–6 mm, 15%; 2–4 mm, 15%; 0–2 mm, 30%). The quality of the steel, with low residual rubber and textile, can be sold for €100/ton, and the rubber crumb has a much larger specific surface than cold-ground crumb, says the company.

The modular system has a throughput of up to 15,000 ton/yr; higher capacities can be increased by adding modules. At €40/ton, production costs are about 25% that of traditional methods, says the company.

Thermal treatment

The sheer volume of automotive waste streams, in particular rubber and plastics is staggering, says Jesse Klinkhamer, CEO, Klean Industries Inc. (Vancouver, B.C., Canada). The current market for applications for recovered rubber, including that from tires, is saturated with old outdated technology and infrastructure that simple cannot handle all of the volume being produced. Although the current market for recovered rubber is growing, the demand for resources and energy far outstrips the need of recovered rubber, he says.

Established in 2005, Klean Industries acquired pyrolysis IP developed in Japan in the 1970s and further developed the technology into a patented, thermal depolymerization process that combines pyrolysis and gasification to convert tires into carbon black, steel and hydrocarbons (Figure 2). The company offers both batch and continuous systems with capacities of 3–500 m.t./d (continuous) and 4–60 m.t./d (batch).

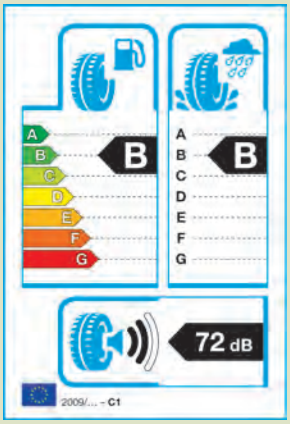
FUEL-EFFICIENT TIRES

Friction between a vehicle's tires and the road is responsible for about 30% of fuel consumption. At the same time, the tires must grip the road, especially when wet, for obvious safety reasons. Finding the right balance between low rolling resistance and strong wet grip is the key to high-performance tires, says Frans Hordies, commercial director Synthetic Rubber, Styron (Berwyn, Pa.; www.styron.com).

A tire is made up of many different components with different rubbers, both synthetic and natural. The tread accounts for the largest portion of synthetic rubber, and SBR (styrene butadiene rubber) is important for the treads. Styron has been developing a solution-based polymerization process to make SBR (S-SBR), and in the last five years we have seen an acceleration in the demand for this rubber, says Hordies. The latest generation of the company's S-SBR — Sprintan S-SBR 4602 — won this years "IQ Innovation Award" for breakthrough rubber technology. "S-SBR is now seen as a key enabling technology for delivering the two contradictory characteristics of low rolling resistance but with the same grip," he says.

Styrol built its first commercial production plant for S-SBR in Schkopau, Germany in 2000, added an additional stream in 2009, and is now constructing a third train scheduled to start up in 4th quarter of 2012. The new production line will introduce an additional capacity of 50,000 m.t. at the production facility in Schkopau.

Lanxess AG (Leverkusen, Germany) also sees high-performing "green tires" as the fastest growing sector in the tire industry, with an annual global growth rate of about 9%, and even higher (14%) in Asia.



Labeling tires for performance

Before November 1, 2012, tire manufacturer's in the E.U. will be required, by law, to declare the fuel efficiency, wet grip and external rolling noise performance of tires for passenger cars, light- and heavy-duty vehicles. The regulation was adopted by the European Parliament and Council in 2009 as a means to trigger fuel savings from the increased use of fuel-efficient tires. The European Commission estimates that between 2.4 and 6.6 MTOE (million metric tons of oil equivalent) can be saved, depending on the speed of market transformation.

Few consumers are aware of the impact of tires on gas mileage, and the Commission estimates that drivers can reduce their fuel bills by up to 10% between the best and worst set of tires available on the market. To increase awareness, tire performances will be displayed at the point of sale and on promotional literature. A standardized tire label (upper label) will inform consumers on three key performance attributes: fuel efficiency and wet grip performance — with a ranking scale of A (highest performance) to G (least performing) — and exterior rolling noise, in both decibels and one to three sound waves (one wave for the quietest, three for the loudest).

In January 2010, The Japan Automobile Tire Manufacturers Assn., Inc. (Tokyo; www.jatma.org.jp) introduced a voluntary standardized Tire Labeling System, which displays performance levels of fuel-efficient tires (lower label). The system grades tires for rolling resistance performance — on a five-scale range from AAA (best) to C (worst) — and on wet grip performance on a four-grade scale from a to d.

South Korea also introduced a similar labeling scheme a few months ago. ❐

"We receive thousands of inquiries on an annual basis for process technology regarding scrap rubber and tires, and have over a trillion dollars of deal flow in our current project-development pipeline," says Klinkhamer. "We simply can't build plants fast enough, even in today's current market conditions."

The company has 15 projects in development pipeline that are either in the permitting phase or entering the permitting phase, and Klinkhamer anticipates that at least seven of these projects will enter into the EPC (engineering procurement construction) phase in the next 18 months, depending on the E.U.'s economic recovery.

Two of these projects are currently operating, and final "hot trials" will be completed at the beginning of 2012. One of these, located in the U.K., is an integrated tire-resource-recovery facility that is supported by several collection centers. Current overall capacity

is approximately 70,000 m.t./yr with 35,000 m.t. being processed thermally and the rest being chipped for TDF, ground for rubber applications and commercial retreading. Ultimately, this facility will recycle 4-million tires per year and produce 3-MW of electricity for export; 5,000 m.t./yr of carbon black; 10,000 m.t./yr of diesel-grade fuel oil; and 3,600 m.t./yr of steel.

The second project, in Ohio, is an integrated commercial truck-tire retreading facility with a capacity of approximately 45,000 m.t./yr with 35,000 m.t./yr being processed thermally and the rest being retreated.

Meanwhile, other pyrolysis processes are progressing toward commercialization. Metso Mining & Construction Technology (Danville, Pa.; www.metso.com), for example, has developed its Tire Pyrolysis System — a continuous process that processes tire shreds, in an indirectly fired rotary kiln, into carbon black, oil, gas and scrap metal.

The company has been operating a 50-kg/h pilot plant at its Pyro Systems Test Center in Danville, Pa. for several years, and the unit has over 1,000 h of operation, says Michael Schiefer, global sales engineer, Pyro. The company is now working on a large application at a brown-field site in the U.K., and includes a complete plant and utilities, he says.

Metso has concentrated on producing carbon black as the economical driver, and maximizing its production, says Schiefer. The company offers a design for continuous operation that is capable of handling 90–100 m.t./d of shredded tires.

Another pyrolysis process for recycling scrap tires, called Formex, has also undergone extensive trials in a 100-kg/h pilot plant in Eisenhüttenstadt, Germany, and a second plant is under construction near Marl, Germany. The process was developed by BOS Berlin GmbH (www.bosgmbh.com), and is being commercialized by abf GmbH (Eisenhüttenstadt; www.abf-engineering.de) (for process flowsheet, see *CE*, March 2002, pp. 27–31).

Microwaves

An alternative thermal recycling process that has taken 18 years to develop is now close to commercialization by its developer, Environmental Waste International Inc. (EWS; Ajax, Ont., Canada; www.ewcm.com). The process, called reverse polymerization, uses microwaves to break the chemical bonds of the rubber. Unlike pyrolysis, in which heat is applied from outside, the microwaves heat from within, explains EWS president Steven Simms. The heating principle is analogous to that used in microwave ovens, but operates at a frequency resonant with hydrocarbon bonds instead of those of water molecules, he says. As a result, the process operates at under 300°C (typically 280°C) compared to 700–800°C typical for pyrolysis. This means less char (burned carbon black) is produced and a higher-quality product is formed, says Simms.

In July, EWS started up its first pilot unit at its Ellsin Environmental facility in Saute Ste. Marie, Ont. The so-called TR900 pilot plant has a capacity to process 900 tires per day. Whole tires are continuously fed into the nitrogen-purged reactor in which about 100 microwave generators cause the rubber to break down and sublimate. Because each generator has its own power supply, it's possible to reduce the power as the depolymerization proceeds. This high degree of control minimizes the formation of char, says Simms.

"Since the unit started in July, we've had visitors from all over the world," says Simms, who anticipates first orders by the end of this year. With delivery times of 10–12 months, the first commercial units could be operating by 2013, he says.

The company is offering a commercial unit, the TR1500, which will process 1,500 tires per day. A modular design means scale up is simply combining two or four units. Investment costs for the TR1500 are around $12.5 million, and Simms estimates a payback period of about three years, "based on very conservative estimates on the value of the products recovered." The economics improves as the cost of oil increases because carbon-black production is directly tied to oil prices, he says. ■

Gerald Ondrey

MAKING WAVES


GE Power and Water

FIGURE 1. Adopting modern chemistries and technologies for monitoring, analysis and control can go a long way toward easing the water treatment burden that is so very challenging for chemical processors

Modern chemistries and equipment are helping chemical processors get a handle on water treatment challenges

For years it has been the common practice to treat process water with various chemistries to prevent scale, corrosion and microbiologicals. However, as regulatory issues tighten, water scarcity becomes a growing concern and the cost of treatment chemicals increases, chemical processors are finding that stringent treatment chemicals are not the only answer. Instead, they're relying upon a multi-prong effort of chemistry, analysis and monitoring to reduce their process-water treatment costs, while keeping in compliance.

"Chemical processors have multiple challenges and priorities when it comes to water treatment," says Kevin Milici, global marketing manager with GE Power and Water (Trevose, Pa.). He says first and foremost is safety and compliance. "If that isn't under control, nothing else is important."

But moving beyond that basic pillar is the issue of avoiding failure in the form of an unscheduled stop in production. "If a unit comes down because of inadequate water treatment practices or controls, that's a bad day for everyone," says Milici. Assuming this is not a problem, the next level is to avoid impaired unit production where the process is running, but in a sub-optimal state — meaning production throughput or yield is less than desired or the cost of producing is extremely high. "Once we make sure impairment of the operation is not an issue, we move onto optimization, which means helping the processor lower the total cost of water operations over time."

Water treatment optimization includes proper chemical dosage and minimization of fresh water consumption, trends that are pushing reduced chemical treatments and water recycling to the forefront (Figure 1).

The idea is to optimize the consumption of chemicals so the proper dosage is being applied, depending upon the actual conditions of the water being treated at that time. "There was a time when people applied chemistry to a system based on the worst case scenario, even if that situation existed only 5 to 10% of the time," explains Milici. However, water quality and discharge regulations have changed and economics have changed to the point where this is not feasible. As a result, processors are now faced with two major challenges. The first is managing the delivery of chemistry so it meets the needs and conditions in realtime by efficiently applying chemicals without sacrificing the operation and safety of the system. The second is reducing the amount of fresh water being used through water reuse or recycling, which also creates chemistry challenges. "Chemical processors — like other industrial water users — are being pushed to conserve consumption of fresh water and, at the same time, to reduce waste streams through water reuse or improving wastewater discharge levels," says Daryl Weatherup, global product manager with Siemens Industries (Phoenix, Ariz.). "This can generally mean using less water throughout the plant, which often requires the combined approach of using higher quality water inside the processing plant and improving the wastewater or water reuse treatment on the back end of the plant."

Meeting the challenges

One of the first steps in optimizing water treatment is through the use of new, improved and environmentally responsible chemicals. "It is the job of water treatment chemistry to enhance an already existing physical process," says Tim Laube, general manager with Kroff (Pittsburgh, Pa.). "It is very possible for water treatment chemicals to enhance and make a process more efficient both in reducing waste and time."

For example, his company has developed polymers that allow for the removal of zinc phosphate in an efficient way. "We can actually reduce how much chemical is fed by as much as 90% in some cases, which has multiple impacts," he says. "First, less chemical is going into the system, which means less chemical has to be removed from the tail end, saving both the cost of the chemicals and the cost of treating the waste stream. Second, the polymers are not toxic, flammable or dangerous, which makes them green, as well as cost and time efficient."

Similarly, Ashland Hercules Water Technologies (Wilmington, Del.) offers Enviroplus advanced cooling-water treatments that both protect plant assets and meet regulatory requirements through the use of environmentally responsible chemistries.

The family includes a series of multifunctional products formulated with novel blends of organic chemistries, which contain significantly lower levels of phosphorus than conventional products. Enviroplus products have a minimal impact on the environment due to the favorable toxicity profiles and inherent biodegradability, yet reduce corrosion and scaling in industrial, alkaline cooling-water systems.

A combination of corrosion inhibitors form a film on metal surfaces, providing corrosion protection without pH control. In addition, a combination of polymeric dispersants and oxidant-resistant organic phophonates provides control of calcium scales.

"This product has the potential to waste less water from the cooling system and minimize total water usage in the cooling system than if using traditional corrosion inhibitors and antiscalants," says Nozi Hamidi, director of global marketing with Ashland.

Another smart, new chemistry system includes, GE Power and Water's GenGard technology for open recirculating cooling systems. The GenGard programs can be applied across the entire pH spectrum from neutral to alkaline and incorporate advanced

PROMISING CANDIDATES ON THE REDUCED- AND CHEMICAL-FREE TREATMENT HORIZON

Emerging market drivers, such as tighter water quality regulations, water conservation and high chemical costs have opened the door for new chemical treatments and non-chemical treatment alternatives that have the potential to give the standard, commodity water-treatment chemicals a healthy dose of competition. Recently, Lux Research (Boston, Mass.) released a report titled "Water Chemicals and Competitors: The Long, Long March of the 'Chemical Free Revolution,'" ranking some of these new and innovative solutions in key treatment markets, including drinking water, wastewater, cooling and boiler water, desalination, mining, industrial and oil-and-gas.

"Opportunities await the new wave of reduced and non-chemical water treatments, but those opportunities are distributed unevenly across application markets," says Brent Giles, a senior analyst with the firm and the report's lead author. "New approaches for treating municipal water, for example, won't budge conventional chemical-based methods. But in the oil-and-gas industry, non-chemical treatments could move very fast because their relatively small footprint enables produced water to be treated at the drill site and reused."

Giles admits that non-chemical treatments almost never completely eliminate chemicals, but technologies like electrocoagulation have the potential to reduce the amount of chemical used, bringing the water much closer to water reuse with less effort. He adds that monitoring plays a big role in chemical reduction because it helps you keep the process in the sweet spot, which reduces the amount of chemicals you are buying and using on the front end and the amount of treatment water you will need on the back end.

Some of the most promising technologies in these areas, according to Giles, include the following:

Water Tectonics, Inc.'s (Everett, Wash.) Wavelonics electrocoagulation technology. The treatment system is an automated, non-chemical water treatment system operating between 100 and 1,000 gal/min for the purpose of removing heavy metals, turbidity, bacteria, phosphorus, chemical oxygen demand and biochemical oxygen demand, sulfides and PCBs.

While it is currently being used in the oil-

and-gas industry, Giles believes electrocoagulation has potential for use in other industries because it effortlessly gets rid of particles in the water. "Heavy particles in water are easily coagulated with this process," he says. "But it may be necessary to treat with chemicals, as well, for very fine particles."

Giles was also a fan of Neosens S.A.'s (Labège, France) monitoring system for preventing fouling in boiler and cooling water. The company's FS-1000 Series for continuous fouling monitoring in cooling systems and critical water processes plugs directly into equipment for realtime monitoring that ensures water treatment efficiency, triggers alerts in case biofilm and or scales abnormally increase, and to optimize and reduce chemical discharges.

The sensor has the ability to continuously monitor the thickness of fouling within the water process, enabling the optimization of treatments and confirmation of treatment effectiveness.

And for those in pharmaceutical manufacturing or any industry with super critical water (SCW) applications, Giles sees a lot of promise in SCFI Group Ltd.'s (Cork, Ireland) AquaCritox SCW oxidation solution. In super critical conditions, the properties of water are changed and the solubility of gases and organic compounds are increased to almost 100%, while inorganic compounds become largely invisible. Oxygen is completely miscible in all proportions with SCW. When a stream containing organic material is placed under super critical condition and oxygen is introduced, a rapid and complete oxidation reaction takes place. This oxidation reaction is exothermic, so the reaction can be auto thermal at very low levels of organic matter. Unlike incineration, the only gaseous emissions from this process are CO_2 and N_2. Phophorous and coagulant can be recovered from the inert residue.

In pharmaceutical applications, the technology does not produce a hazardous concentrate that would normally require disposal. While biological treatment processes produce a waste sludge that requires disposal, the AuqaCritox process produces an effluent liquid stream with low chemical-oxygen-demand (COD) values. Any inert material within the waste stream will exit the process as inert residue.

"This self-perpetuating wastewater treatment eliminates complex organics through complete oxidation while allowing for the retrieval of metals and phosphates," says Giles. ❐

deposit and corrosion additives. The technology includes a new stress tolerant polymer (STP), alkaline enhanced chemistry (AEC) and halogen resistant azole (HRA) in combination with phosphate-based steel corrosion inhibitors. The treatments are stable and retain effectiveness in the presence of chlorine and other halogens,

Siemens

FIGURE 2. The Siemens Micro/2000 measurement module measures free and total chlorine residual, chlorine dioxide, ozone or potassium permanganate residuals in potable water, primary or secondary treated wastewater or cooling water

allowing Legionella compliance when chlorine and bromine residuals are continuously applied at levels for general microbiological control and during periodic system disinfections. Unlike conventional treatments, GenGard allows users to effectively respond to microbial upsets without a loss of deposition or corrosion control.

Fluid Metering, Inc.

FIGURE 3. Accurately metering liquid sodium hypochlorite presents challenges, but the Chloritrol system's valveless duplex-pump design allows sodium hypochlorite directly into the water main, while a second pump removes out-gas bubbles. Dosage equipment such as this can help processors optimize water treatment programs

Dosage, monitoring & analysis

While smarter and more environmentally friendly chemicals are a step in the right direction, the sustainable trend is also moving processors toward reducing the amount of chemicals added during the treatment process, notes Weatherup. "Proper dosing, monitoring and control is the best way to approach this desired reduction of chemical waste," he explains.

Manoj Sharma, vice president, products and services division with Aquatech (Canonsburg, Pa.) agrees. "An effective water-treatment chemical program is a key contributor in optimizing water consumption and improving overall system efficiency," he says. "But the program is even more effective if it is combined with innovative water treatment systems that include hardware. The optimization of integrated chemical and efficient treatment equipment is commonly defined as total water management."

The reason this approach is so effective, according to Stephan Andree, global product manager of analysis and control equipment with Siemens, is because it helps reduce the amount of chemical usage. "Automation of chemical fed processes through the addition of a high quality dosing pump, analyzer and control equipment can reduce chemical use by 30%, versus leaving it without proper control and feed equipment," he says. "Automated feed equipment cuts over and under dosage of chemical, which helps save the cost of chemical, as well as reduces unnecessary chemical usage, making treatment and or reuse more efficient."

A prime example of this type of equipment is Siemen's Micro/2000 Measurement Module Analyzer (Figure 2), which provides a user-friendly display and touch pad with historic data trending. The unit can be con-

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SCFI Group	www.scfi.eu
Water Tectonics	www.watertectonics.com

figured for different operating ranges, alarm set points and display information for continuous measurement of oxidant residuals. The measurement module measures free and total chlorine residual, chlorine dioxide, ozone or potassium permanganate residuals in potable water, primary or secondary treated wastewater or cooling water. It is able to measure low oxidant residuals down to 1 ppb.

And, Ashland's OnGuard 2-plus analyzer monitors critical cooling-water and heat-exchanger performance indicators and parameters, including corrosion, fouling, pH, conductivity, temperature, oxidation reduction potential and water flow, and provides realtime measuring and process control.

The analyzer is able, instantly and remotely, to compare existing conditions to defined targets and then adjust automatically to close the gap, provide immediate response to system upsets and provide accurate reports.

GE's offering in the monitoring and analysis arena includes TrueSense, a technology platform that assists users with optimization through monitoring of chemical usage, water use and consumption, operational productivity and human productivity. The online version was designed to provide a direct measurement of functional chemistries that drive success for all dimensions of cooling water management. The platform takes measurement and control technology for multiple analytes using a single detection platform that offers simplicity and stability. The solution can be designed to meet specific goals of a particular water-treatment plan and budget.

Experts agree that adopting these or similar modern chemistries and technologies for treatment, as well as monitoring, analysis and control, can go a long way toward easing the water treatment burden that is so very challenging for an industry where the main concern is producing high quality products and minimizing downtime. "Embracing newer technologies really can reduce the challenges, as well as cost issues, for chemical processors for whom water treatment, reuse and recycling is not a core practice," says Hamdini. ■

Joy LePree

Fractionation Column

Believe your instruments, unless...

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

I was having a "wallflower moment" after Ms. Ruth Sands' excellent troubleshooting presentation at the March AIChE meeting. That presentation was well summarized by Editor in Chief, Rebekkah Marshall in the April issue of *CE* (p. 5). I wanted to tell Ms. Sands, and the other meeting attendees, about my solvents column troubleshoot. Here's the story:

On this particular troubleshoot, the only thing that I knew for certain, was that I knew nothing for certain. The column owner complained about poor performance. Operating data revealed an enthalpy imbalance — the column was accumulating heat at an amazing rate — or not. The top tray was hotter than the bottom tray — or had the column been installed upside down, with the reboiler at the top?

Admittedly, I knew where the column was located, and after a long flight, I found it. Several engineers and technicians were there to assist me. The control room consensus was this: The separation was poor because the trays were operating near their flood points. Back in my U.S. office, I had concluded that the pressure drop data were wrong. A pressure drop of 0.5 psi across 50 trays was simply not believable. As a general rule, the pressure drop across a well-functioning tray is 0.1 psi per tray.

After two days of onsite calculations, technician interviews and operating-manual reviews, I had a theory that I was feeling good about: The reflux and steam meters were both wrong and the pressure drop data were correct. I stated, "I believe that your column is functioning at about 10%, not 90%, of the design loadings and that is why your separation is so bad." The control room response was, "but this is where we have operated this column ever since its commissioning 10 years ago!"

I requested that the reflux and steam rates be increased by a factor of eight or nine. They held an "employees only" meeting and told me that an important man would have some very serious questions for me the next day.

After a long evening of corroborative calculations and a semi-sleepless night, the troubleshooting team assembled in a meeting room in the control building at 9 a.m. Few spoke, including me. An important man entered the room, clearly unhappy to be there. He stated, "Mr. Restarts [SIC], I am the plant safety director and WE have very serious safety concerns regarding your proposal to increase the steam to the solvents column by almost 10 times." He held up ten fingers. I said to myself, "What?". I said to the safety director, "What?" He repeated himself. I said, "I am definitely not requesting increasing the column operating pressure. A steam rate increase will not present any safety hazards."

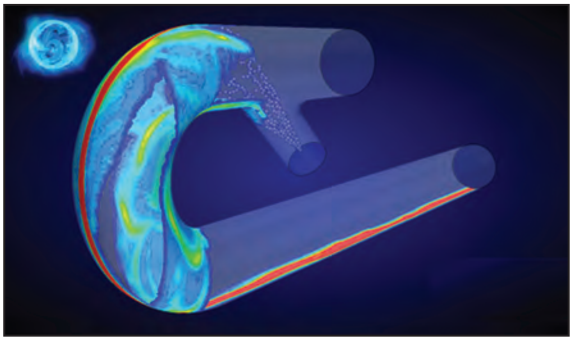
The Column operators held another "employees only" meeting and thereafter reluctantly agreed to increase the steam rate by 10% per day, until the column became "unsafe." About one week later, the column was achieving its best separation ever, the pressure drop was around 0.10 psi per tray and the reflux meter never budged from its pre-Restarts value. Restarts was a hero.

In March, Ms. Sands stated, "Believe your instruments unless you have a good reason not to." Generally, she is right, but she never tried to blow a relief valve by increasing a reboiler steam rate. ■

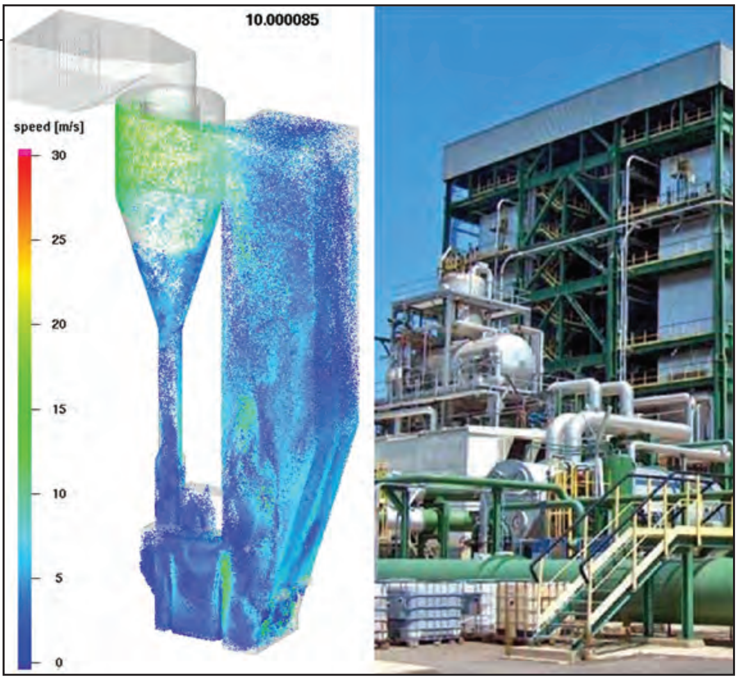
Mike Resetarits, resetarits@fri.org

FOCUS ON

Engineering Software



CD-adapco



CPFD Software

More physics means more applications with this CFD software

STAR-CCM+ Version 6.04 is this company's latest release of its CFD- (computational fluid dynamics) focused engineering simulation software (photo). The new release aims to: further expand the application coverage through the addition of new, validated physics; to further improve quality, robustness and speed of the meshing technology; and to enhance usability of 3D-CAD (computer-aided design), the surface-preparation tools, the CAD clients and the visualization capabilities. For example, heat and mass transfer between phases have been added to the Existing Eulerian multiphase capabilities. The new release also includes, among other additions, a new model to predict the formation and transport of thin liquid film on a surface, and its subsequent stripping and breakup under aerodynamic forces. — *CD-adapco, Melville, N.Y.*
www.cd-adapco.com

Expanding applications with this multiphysics software

May saw the release of the latest version of Multiphysics — Version 4.2 — which incorporates three new applications modules: Microfluidics, Geomechanics and Electrodeposition. For example, the Microfluidics Module can be used for the study of microfluidic devices and rarefied gas flows, and can be used for the design of lab-on-a-chip devices, digital microfluidics, electrokinetic devices, inkjets and vacuum systems. This release also has new LiveLink interfaces for AutoCAD and SpaceClaim. Version 4.2 includes new virtual geometry tools for creating a mesh that identifies the essential parts of the original CAD model to enable faster and more memory-efficient solving. Time-dependent adaptive meshing and automatic remeshing tightly link solvers and meshing algorithms for any moving mesh analysis. — *Comsol, Inc., Burlington, Mass.*
www.comsol.com

Particle and fluid flow are modeled by this software

Barracuda V14.4 is the latest CFD software specialized for modeling fluid-particle flow problems in industrial applications. This latest version provides the ability to predict erosion in chemical plant equipment caused by particle-wall impacts. Based on this company's CPFD (computational particle fluid dynamics) numerical methods, which combine a Eulerian approach for the fluid with a Lagrangian formulation for the particles, Barracuda is a specialized form of CFD designed specifically for modeling reacting fluidized systems (photo). Because solids are treated as discrete particles with a full particle-size distribution, Barracuda is able to calculate an erosion index based on the individual particle mass, velocity and impact angle with solid surfaces. High-wear locations can be identified, whether the surface is metallic or refractory-lined, and the software can be used to predict the impact on erosion rates of changes to the design or operating conditions. Barracuda is widely used for the modeling of circulating fluidized beds, fluidized-bed reactors, fluid catalytic-cracking units and other gas-solid or liquid-solid processing equipment. — *CPFD Software, Albuquerque, N.M.*
www.cpfd-software.com

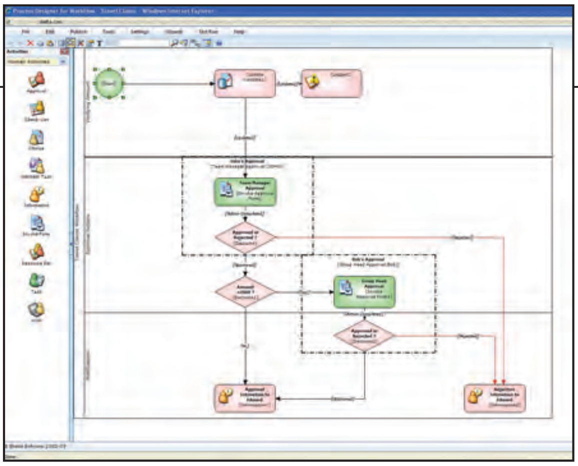
More worksheets for engineering calculations

This company recently added more than 600 new Parametric Technology Corp. (PTC) MathCAD worksheets from PTC e-Libraries. The worksheets are fully compatible with MathCAD 14.0, 15.0 and MathCAD Prime 1.0. The Knovel Math expansion enables engineers to quickly find and solve systems of equations across a wider range of topics via a collection of fully documented and validated MathCAD worksheets. — *Knovel, New York, N.Y.*
www.knovel.com

Improve crystallization processes with this modeling tool

gCrystal is a powerful and user-friendly tool that uses high-fidelity predictive models validated with experimental or operating data to provide accurate information for support of design and operating decisions. The software helps scientists and engineers responsible for the design and operation of crystallization processes to meet crystallization challenges through: population balance model-

Note: For more information, circle the 3-digit number on p. 70, or use the website designation.



Invensys Operations Management

ing to represent the crystal size distribution; representing key phenomena (such as primary and secondary nucleation, growth, attrition, agglomeration and breakage) with detailed first-principles models; a built-in capability to link with CFD models to capture hydrodynamic effects for reliable scaleup; and more. The software can lead to increased throughput, improved product quality, reduced scaleup risks and more. — *Process System Enterprise Ltd., London, U.K.*
www.psenterprise.com

Improved workflow for all, regardless of where they are

ArchestraA Workflow Version 1.1 (photo) is this company's latest business-process-management solution for industrial enterprises. The new version adds Integration to IntelaTrac, the company's mobile solution, and its Wonderware MES (manufacturing execution system) Operations and Performance solution. The workflow software helps computerize manual and automated processes that involve people and systems, allowing workers to participate in approved workflow, regardless if they are mobile, behind a desk or operating the plant. — *Invensys Operations Management, Plano, Tex.*
http://iom.invensys.com

Major enhancements in the latest release of ChemCAD

With an intuitive interface and extensive libraries of chemical components, thermodynamic methods and unit operations, ChemCAD extends the engineer's process simulation capabilities. This company is committed to ongoing, client-led product development, as evidenced by the many improvements in ChemCAD 6.4, released last July. New features include Thermo Acceleration Mode, which helps speed complex calculations, and improved dynamic column performance and topology reporting. Users can now regress BIPs (binary interaction parameters) from partial pressure data, and can specify more properties when defining their own components. — *ChemStations, Inc., Houston*
www.chemstations.com

Enhanced design software further streamlines workflow

AutoPlant V8i (Select Series 3) — the latest version of this company's AutoCAD-based plant-design software

— is fully compatible with 64-bit AutoCAD, Windows and Microsoft Office. The AutoPlant products include specification-driven, 3D design tools for piping, equipment, isometric, raceway and steelwork design, along with 2D functional-design applications for instrumentation, wiring, data sheets and process-and-instrumentation diagrams. The new enhancements to V8i further streamline workflows, improve information sharing and engineering content management, reduce risk, facilitate more effective change management and lead to higher quality projects, says the company. — *Bentley Systems, Inc., Exton, Pa.*
www.bentley.com

Turn laser-scan data into an accurate, 3D plant model

An integral part of this company's larger laser-scan strategy, Laser Modeller rapidly and cost-effectively transforms laser scan data into intelligent, as-built 3D plant models. Creation of an accurate 3D model allows owner operators to optimize the operation of their assets and significantly reduce the lead time on upgrade and revamp projects in a way that is not possible with historic applications, says the company. Laser Modeller can accept scan data from any of the leading laser scanner vendors. It directly generates 3D models to feed into a visual asset-management strategy. For brownfield projects, using native PDMS component catalogs, it delivers a fully intelligent PDMS model. — *Aveva Group, Plc., Cambridge, U.K.*
www.aveva.com

Something new for everyone with this release

Released in May, AspenONE 7.3 engineering software features new optimization innovations for exploration and production, petroleum refining, chemicals and other process industries. A new, patent-pending Conceptual Design Builder in AspenHYSYS Upstream builds gas-oil separation plant models in minutes, reducing risk when evaluating upstream asset design options. Rigorous plate-fin and spiral-wound heat exchanger models inside HYSYS allow companies to optimize LNG (liquified natural gas) plants, analyze operational challenges and deliver solution alternatives. The new Assay Library of 180 crude oils enables refiners to characterize multiple crudes more accurately and efficiently. The Aspen Fired Heater equipment models inside HYSYS allow refiners to study operational constraints, predict revamp benefits and increase energy savings. The new Properties Mobile delivers access to physical-property data to mobile devices. — *Aspen Technology, Inc., Burlington, Mass.*
www.aspentech.com ■

Gerald Ondrey

CHEMICAL ENGINEERING
FACTS AT YOUR FINGERTIPS
Department Editor: Scott Jenkins

Sterilization Approaches

TABLE 1. COMPARISON OF STERILIZATION TECHNIQUES		
Sterilization technique	**Advantages**	**Disadvantages**
Moist heat (steam)	Inexpensive, highly effective and efficient, non-toxic	Degradation of material, safety
Ethylene oxide	Low-temperature applications, highly effective and efficient	High-temperature applications, cost, safety
Ionizing radiation	High molecular-weight durability, highly effective and efficient	Low oxygen permeability, cost, safety
Plasma	Wide range of compatibility, high effectiveness	Lack of experience with plasma, cost
Dry heat	High penetrating power, low corrosion	Temperature stratification, slow heating rates, high temperatures, long exposure times

Maintaining high-purity conditions in the chemical process industries (CPI) depends in large part on the techniques used for sterilization. As a method to inactivate or eliminate potentially harmful microbes, sterilization can be achieved through a number of different approaches, such as moist-heat (steam), radiation, ethylene oxide treatment and newer technologies. Each approach has advantages and disadvantages, and the choice can have a major impact on product quality and safety.

Ethylene oxide sterilization

By virtue of its being a gas at ambient temperature and pressure, ethylene oxide (EtO) can be used in lower-temperature applications, and is considered to be the "gold standard" for low-temperature sterilization. Biologically, EtO works by alkylating DNA, which disrupts cellular processes. This makes EtO effective against bacteria and fungi, as well as against microbial spores.

The properties that make EtO an effective sterilizing agent also make it a danger to those who may be exposed to the compound. However, EtO has been used in the healthcare industry for a relatively long period, so the chemical is well regulated, and many safety systems have been developed.

Because of EtO's high reactivity, it may be undesirable in some process situations. Therefore, detailed research is recommended before incorporating EtO into a process as a sterilization agent.

Ionizing radiation

Using short-wavelength radiation to disrupt covalent bonds can be an effective method to sterilize materials and surfaces, including polymers. Ionizing radiation generates reactive species in cells that disrupt microbial DNA. The three-step interaction of ionizing radiation with biological and chemical matter consists of a physical stage, in which radiation is absorbed; a physicochemical stage, where thermal equilibrium is established within the system; and a chemical stage, when the reactive species diffuse and react with adjacent molecules. All three stages occur within microseconds, making the overall ionizing radiation process highly time-efficient, while still maintaining a high level of thoroughness.

A significant disadvantage of the techology is its safety to individuals. Also, care must be taken to ensure that the irradiation does not have a deleterious effect on the product or material being exposed.

Moist-heat sterilization

Another common sterilization method is to use steam to deactivate microbe cells by denaturing cellular proteins and other macromolecules. Steam sterilization is widely used because of its high efficacy, low reactivity and low cost. One tool for steam sterilization is an autoclave, where a chamber is filled with steam at an optimal temperature and time to maximize killing of microorganisms. Related are steam-in-place (SIP) systems that use steam to cycle through tanks, pipes and equipment. In that case, a cleaning solution is introduced to the tank or pipe system, followed by a rinse with purified water and then steam.

A disadvantage of using a steam sterilization system is that steam cycles can be long (~4 h). While sterilization itself usually takes 20 min at 121°C, preconditioning time is required to eliminate air in the chamber, as is drying time following the sterilization. Another challenge is the sterilization of complicated components with contaminant-trapping designs.

Effective steam sterilization requires a robust steam-delivery system that is capable of supplying steam dry enough to penetrate components, but also wet enough to coat surfaces sufficiently. It is usually desirable to have steam generation occur close to where it will be used in an autoclave.

Dry-heat sterilization

Sterilization can also be accomplished with dry heat, through the use of a large-scale, convection-heating industrial oven. Convection heating occurs when heat is transferred through a medium by motion of its parts. Industrial convection ovens are critical for high-efficiency particulate air (HEPA) filtration. In such applications, air is heated by the heating elements of the oven by natural convection and transferred into the air by forced convection. Dry-heat sterilization kills microbes by coagulating proteins at elevated temperatures.

Relatively little research has been carried out in the area of dry-heating sterilization because the process is time-consuming and difficult to control. These difficulties arise because of temperature stratification and slow heating rates.

Dry-heating does have some advantages compared to moist-heat sterilization, however. These advantages include a higher penetrating power, less corrosivity and slower erosion of ground-glass surfaces compared to steam sterilization. Dry-heat sterilization has become more widely used in recent years because of advancements in infrared-radiation tunnels that have started to remove a downside of dry heat by allowing high-heat, short-time sterilization.

Plasma-based sterilization

Plasma (ionized gas) is created by applying an electromagnetic field to a gas. The electromagnetic field creates a range of particles, including photons, electrons and neutral particles. The active agents of plasma sterilization are ultraviolet (UV)-wavelength photons, as well as free radicals (usually oxygen species with unpaired electrons). Hydrogen peroxide in an evacuated chamber is often used as the source of the radicals in plasma sterilization.

The mechanism by which microorganisms are killed with plasma irradiation is tri-phasic. The first component is UV irradiation, which damages microorganism DNA directly. The second is photodesorption, whereby UV photons break bonds in the material making up the microbes, leading to formation of volatile byproducts, which are removed. The third phase involves adsorption of reactive species onto the microorganism. The reactive species undergo chemical reactions to create volatile small molecules. When a sufficient level of material has been removed, and DNA damaged, the microbe dies.

An advantage of using the plasma sterilization method is the potential for maintaining relatively low temperatures (≤50°C), which allows the integrity of polymer-based materials to remain intact. Also, plasma sterilization is safe for the operator, and leaves no toxic or harmful chemical residue. Sterilization cycles for plasma can be relatively short.

References

1. Baez, H. A. and Assaf-Anid, N.M., Novel and Conventional Approaches to Sterilization, *Chem. Eng.*, August 2008, pp. 42–45.
2. Moisan, M., Barbeau, J. and others, Plasma Sterilization: Methods and Mechanisms, *Pure Appl. Chem.* vol. 74 (3), pp. 349–358, 2002.

Editor's note: This edition of "Facts at Your Fingertips" is partially adapted from the article referenced above [*1*].

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

NO SMALL ACHIEVEMENT:

SELLING MORE WITHOUT GOING BROKE

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

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

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

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The person pictured is an actual PNC customer, who agreed to participate in this advertisement. Loving Pets' success was due to a number of factors, and PNC is proud of its role in helping the company achieve its goals. **1** All loans are subject to credit approval and may require automatic payment deduction from a PNC Bank Business Checking account. Origination and/or other fees may apply. Banking and lending products and services and bank deposit products are provided by PNC Bank, National Association, a wholly owned subsidiary of PNC and **Member FDIC.** Bella Bowls is a registered trademark of Loving Pets Corporation. BBK-5025 ©2011 The PNC Financial Services Group, Inc. All rights reserved. PNC Bank, National Association. **Member FDIC**

McINNES
ROLLED RINGS

CHEMINNOVATIONS 2011 CONFERENCE & EXPO

GEORGE R. BROWN CONVENTION CENTER
HOUSTON, TEXAS SEPTEMBER 13 – 15, 2011


Rosedale Filtration Products

Exhibitors and attendees alike are getting geared up for the 2nd annual ChemInnovations Conference and Expo (www.cpievent.com), which runs from September 13–15 at the George Brown Convention Center in Houston. Focused on breakthrough ideas, emerging technologies and game-changing solutions in the chemical process industries (CPI), the event offers the most comprehensive conference content for chemical engineers in North America. ChemInnovations 2011 is expected to draw over 150 exhibitors and more than 2,500 attendees. The event is co-located with three others — the annual meeting of the International Society of Automation (ISA) Houston Section, the Pump User's Symposium and the Turbomachinery Symposium.


BHS Filtration

Conference tracks

Six tracks, plus the Chementator Lightning Round (*Chem. Eng*., Aug. 2011, p. 20D-1) comprise ChemInnovations' conference program:

- ***Track 1***: Business insights, outlook and regulatory issues
- ***Track 2:*** Process, design and operations
- ***Track 3:*** Environmental, health and safety
- ***Track 4:*** Energy efficiencies and the use of alternative energy sources
- ***Track 5:*** Equipment maintenance and reliability
- ***Track 6:*** Instrumentation, controls and automation

PRODUCTS AND SERVICES

The following descriptions include some of the many products and services that will be featured on the exhibit floor at ChemInnovations.

Achieve high-performance filtration with a compact design

This company's high-flow filtration systems (photo) are available in a variety of sizes to accommodate one to 18 filter elements in 40 and 60-in. lengths. Flowrates achieved are up to 400 gal/min. With a horizontal style, the system maximizes the ease of operation while minimizing the physical footprint. The high-flow filtration systems have standard pressure and temperature ratings to 300 psig and 250°F. The hinged cover permits easy changeouts and the units are available in carbon steel, as well as 304 and 316 stainless steel. Booth 3106 — *Rosedale Filtration Products Inc., Ann Arbor, Mich.*
www.rosedaleproducts.com


Robatel

This centrifuge is designed for R&D and small-scale processing

Laboratory centrifuges from this company (photo) are ideally suited for R&D, as well as small-scale processing. They can be equipped with three different-sized interchangeable rotors for processing multiple batch sizes. The centrifuges offer basket filtration and solid-liquid sedimentation, and hard- or soft-sided containment systems can be installed for use with potent compounds. Cart-mounted installation allows for easy portability. They are available with explosion-proof electrical controls and can be constucted from 316L stainless steel, Hastelloy C and others. Booth 316 — *Robatel Inc., Pittsfield, Mass.*
www.rousselet-robatel.com

A touch-screen for interlock systems

The new CKC Touch-Screen display for key interlocking systems is designed for integration into interlock key cabinets, or for separate mounting as a standalone feature. All cabinet

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

CHEMINNOVATIONS 2011 SHOW PREVIEW II

– SPECIAL ADVERTISING SECTION – **PREMIUM EXHIBITORS**

Biar S.A.,

BIAR is a Swiss-based manufacturer of Sampling Valves for pipelines and reactors since 1980. Designed to meet the highest security standards, our product is the professional solution for all liquid and gas sampling requirements. The modular design provides an exposure-free environment without dead space, hanging drop or soiled surface. We guarantee directly representative samples in a simple, safe and efficient way.

www.biar.com

Continental Disc Corp.

The HPX™ rupture disc is a scored reverse acting rupture disc. This differential pressure relief device features an instantaneous full-open relief area for protecting equipment, vessels, systems and people from an overpressure condition. This high precision reverse acting rupture disc offers proven performance in excess of 250,000 cycles at a 95% operating ratio.

www.contdisc.com/en/component/products/detailProdGroup/11/HPX%E2%84%A2-Rupture-Disc-Product-Family.html

Emerson Process Management

Chemical producers share many of the same challenges – ensuring safety, availability of production assets, optimized production, and efficient energy management. Just as no two chemical operations are alike, there is no standard solution for meeting these challenges. At Emerson Process Management, we have the right technology and expertise to help you create a solution as unique as your process.

www.emersonprocess.com

Feluwa Pumpen GmbH

MULTISAFE Double Hose-Diaphragm Process Pumps

At the heart of this pump are two hydraulically actuated hose-diaphragms which are arranged one inside the other. They enclose the linear flow path of the fluid and create double hermetic sealing from the drive end. The product is not in contact with the pump casings, so that these can be made from lesser materials.

www.feluwa.com

Honeywell

Honeywell is the automation technology leader in the Chemicals market with a full portfolio of scalable solutions tailored to meet the customers business challenges by enhancing safety, reliability, efficiency and sustainability.

Honeywell products range from process knowledge systems, to instrumentation, sensors, batch and advanced control, safety, MES, and asset management solutions. Our services include consulting, project, and lifecycle management.

www.honeywellprocess.com

Leser

Headquartered in Germany, with a state of the art factory and more than 500 employees globally, LESER supplies high quality safety valves worldwide. LESER manufactures 7 different product groups and 38 valve types. A variety of materials and sizes provide safe solutions for virtually every industrial safety valve application.

www.leser.com

Oseco

Oseco rupture discs offer industry best flow characteristics.

Oseco's ASME UD stamped, forward acting FAS rupture disc and reverse buckling PRO+ offer the lowest KR available in today's process industry. The FAS and PRO+ are primarily used to isolate safety relief valves. The FAS is used in high pressure applications, while the PRO+ is ideal for high cycling applications.

www.oseco.com for the link.

People and Processes, Inc.

People and Processes, Inc. is an education and consulting services firm dedicated to Maintenance and Operations enhancement. We help our manufacturing and facilities clients by utilizing industry recognized best practices and processes in a holistic site approach.

Since we measure our success on your results, we believe in partnerships with our clients. It's about your success.

www.peopleandprocesses.com

ProMinent Fluid Controls, Inc.

ProMinent Fluid Controls, Inc. is a global manufacturer of chemical metering pumps, water quality instrumentation, specialized disinfection equipment, and pre-engineered or custom skidded systems serving the Water and Wastewater industries. We have proudly served the Municipal, Industrial and OEM markets in the United States for over 30 years.

www.prominent.us

Rosedale Product

Rosedale Products manufactures a complete line of filtration equipment including bag filters, cartridge filters, basket strainers, automatic back washing systems, as well as custom pressure vessels and tanks. Rosedale maintains a large inventory of ready-to-ship housings.

www.rosedaleproducts.com

RSC Equipment Rental

RSC's Integrated Services is a specialized equipment and tool rental program that gives you centralized administrative control over your entire organization's rental requirements and transactions through our Total Control® Management Software, Managed Services, Mobile Tool Room™ and Pump and Power Solutions.

www.rscrental.com/default.aspx

RVT process Equipment, Inc.

Company Profile: RVT Process Equipment designs and delivers innovative products to the chemical, petrochemical, and refining industries. RVT has offices in the USA, Germany, & China.

www.rvtpe.net

USA Industries Inc.

Turnaround Product Specialist Available 24/7. Products include Snap It® Sr and Jr plugs; metal tapered tube plugs in all alloys and sizes; Piping Isolation Products include Blinds, Spacers, Flange Test Plugs, Blind Flanges, Isolation Plugs, EZ Vent and EZ Purge Blinds; Portable Machine Tools; and Heat Exchanger Tools. Many products available for rental or sale.

www.usaindustries.com

Valve Concepts Inc.

The 8900 Series manway pressure and pressure /vacuum relief vents provide emergency pressure relief beyond that furnished by the normal pressure vent for atmospheric and low pressure tanks. Pressure pallet assembly designed so it can be removed to allow unobstructed access to tank. Set point pressures from 0.5 psi to 15 psi. Vacuum set points from 0.2 to 4 oz/in2. Sizes 16" thru 24" in aluminum or stainless steel construction.

www.cashcosolutions.com/products.php?sID=90&pID=101

ISE Magtech

LTM-350 "INTELLIGAUGE" Magnetostrictive level transmitter unleashes the power of HART-7, with wireless capability, time stamped data, increased diagnostics.

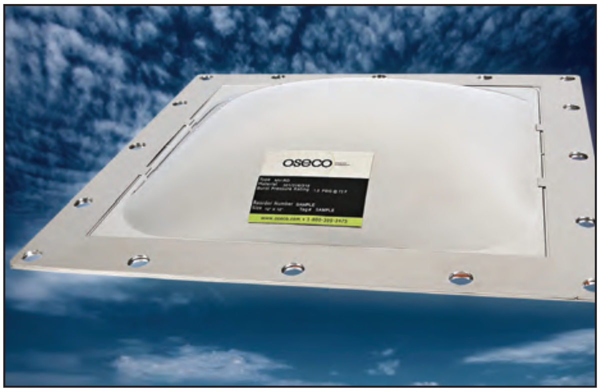
"INTELLIGAUGE" transmitters mount externally to any LG series Magnetic level gauge or serve as a direct insertion type. This unit has multiple outputs.

HART Registered Device
Dynamic RoC Filter
Power Optimization Software
Simple Configuration
Factory set threshold
Field-reversible mounting
Auto detect configuration errors

www.isemagtech.com

keys are displayed on the screen, and a single touch can provide detailed information about that specific key and its corresponding interlock system. The touch-screen also includes additional information buttons that provide access to facility contact details, operating manuals, product information and training instructions. Booth 3020 — *Netherlocks USA, Houston*
www.netherlocks.com

Protect personnel and equipment with this explosion vent


Oseco

The new MV-RD explosion vent (photo) is offered for protecting personnel and equipment during deflagrations in high-cycling and high-vacuum applications. The vent provides extended in-service life, lower burst pressure in smaller sizes and an industry-first, two-year warranty. The MV-RD is designed for high-cycling applications, such as in dust collectors and bag houses that experience vacuum pressures up to 12 psig. The vent mounts on enclosures where dust explosions may occur, and will activate to safely relieve pressure in the event of a deflagration, thereby preventing a large explosion. The vent can also be used on bulk storage units and in ductwork applications requiring a square explosion vent. Unlike other domed vents, the MV-RD can operate in temperatures up to 450°F. Booth 3301 — *Oseco, Broken Arrow, Okla.*
www.oseco.com

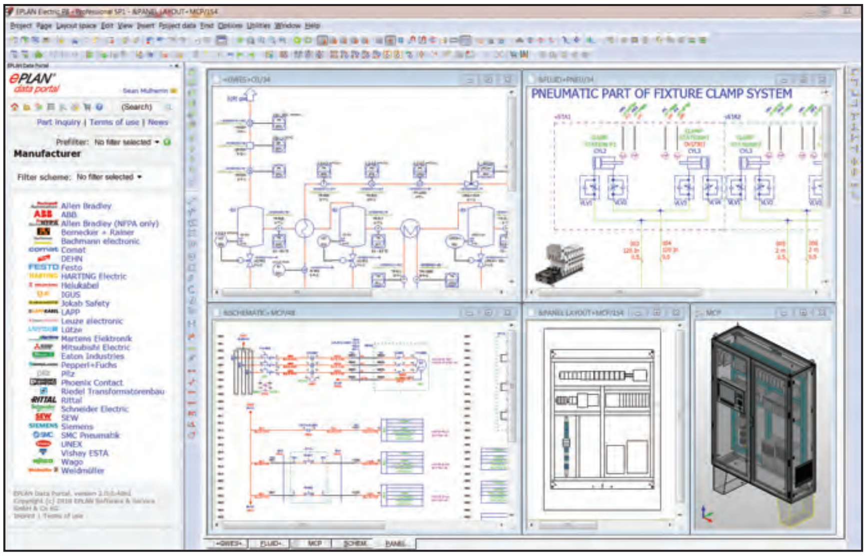
This belt filter has a large area

With a 3.50-m-wide belt, this company's belt filter (photo, p. 32D-1) offers 73.5 m^2 of filter area. The belt filter is capable of handling a range of filtration applications, as well as washing and drying of high-value product in an alkaline slurry. The unit also features a candle filter system to recover fines and recombine them into the process, thus maximizing product recovery. Booth 3325 — *BHS Filtration Inc., Charlotte, N.C.*
www.bhsfiltration.com

V. 2 of this hardware-design software features improvements

Version 2.0 of this company's hardware design software (photo, p. 32D-4) contains updates that improve the generation of schematics, as well as documentation management. More complex device technology has increased the need for software to clearly

CHEM INNOVATIONS 2011 CONFERENCE & EXPO



EPlan Software and Service

represent electrical wiring and connections in design schematics, and the new software version includes mechanisms to do so. The software also includes more powerful revision control for design documents, with a system of colors and symbols to make it easier for users to quickly see all types of changes made. Langauge management is another area where the new version has improvements; users can now differentiate between the source language and the display language in a project. The software makes language translations more transparent. Booth 3239 — *EPlan Software and Service GmbH, Monheim am Rhein, Germany*
www.eplan.com

These all-electric actuators have wireless technology

This company's CVA control-valve actuators (photo) offer precise operation, along with wireless Bluetooth communication technology that can be used for quick setup and valve adjustment. With high repeatability and a resolution of less than 0.1% of full-scale, the CVA actuators are suitable for a wide range of control-valve applications. They are available with quarter-turn and linear actions, feature advanced human-machine interface capabilities, and can be specified for single-phase a.c. or d.c. electrical supplies. Booth 3413 — *Rotork Controls Inc., Rochester, N.Y.*
www.rotork.com

Rotork Controls

Pumped fluid is sealed to prevent leakage to atmosphere

The latest pump from this company is the Zero Emission model (photo, p. 32D-5), where the pumped fluid is hermetically sealed within the pump, preventing leakage to the atmosphere during operation. The unique, packing-free, dynamic-seal design enables safe, reliable and continuous-duty operation. The intermediate chamber of the pump can be outfitted with gastight covers that provide a seal to the atmosphere. The chamber can then be charged with inert gas if required. The integral speed reducer has twin helical gears arranged in a herringbone configuration to ensure smooth running and even-power transmission without

Hammelmann

SafePlex Systems

axially loading the bearings. Booth 3412 — *Hammelmann Corp., Dayton, Ohio*
www.hammelmann.com

Heat-transfer fluids with a variety of properties

Liquid-phase heat-transfer fluids from this company are available with properties that suit a broad range of process applications. Among the options are synthetic fluids for high- or low-temperature applications, and for applications requiring a large temperature swing. Other fluids are mineral-oil based, or designed specifically to allow vapor-phase heat transfer. The company also offers a flushing fluid to help clean interior surfaces of heat-transfer-fluid systems. Booth 3124 — *Solutia Inc., Houston*
www.therminol.com

An ESD valve controller with a fault-tolerant design

Designed for controlling emergency shutdown (ESD) valves, the SILstroke-3B (photo) features parallel air supply and air venting pathways that allow a fault-tolerant, failsafe design. The SILstroke-3B is certified by TÜV Rheinland to achieve safety integrity level (SIL) 3. Installation of the ESD valve controller is easy, the company says, and its reliability enables operators to lengthen the proof-test intervals for ESD valves by up to five times. Booth 3125 — *SafePlex Systems Inc., Houston*
www.safeplexsystems.com

This company has expertise in pinch analysis

Maximizing energy recovery from chemical processes using pinch analy-

sis is among the areas of expertise of this international engineering, procurement and construction management firm. The firm's engineers have decades of experience in the design and development of chemical processes. Representatives from this fast-growing firm will be on hand at ChemInnovations to provide information about the company's capabilities. The firm has been recognized as among the leaders in "green" construction. Booth 3119 — *SSOE Group, Houston*
www.ssoe.com

This heat-exchanger design software has new additions

Xchanger Suite 6 software includes components for the design, rating, and simulation of heat exchangers and fired heaters. Methods contained in the software calculations are integrated into the Windows interface, and supported by the extensive data collected from industrial-sized heat transfer equipment. HTRI Xchanger Suite components are flexible, allowing rigorous specification of exchanger geometry. This capability optimizes the use of HTRI's proprietary heat-transfer and pressure-drop correlations. A new service pack for Xchanger Suite 6 is now available. Booth 3006 — *Heat Transfer Research Inc., College Station, Tex.*
www.htri.net

This position indicator offers high visibility

The 1235 Position Indicator (photo) is designed for difficult installations where the local indication may be obscured in some way, or where the short stroke of fractional size values may result in lack of positive definition. The unit's position-indicating switch can be mounted on most available linear valves, and has highly visible local indication. The unit is hermetically sealed, and can be programmed locally or remotely without removing the cover. Booth 3423 — *Gemü Valves, Actuators and Control Systems, Atlanta, Ga.*
www.gemu.com

Gemü Valves

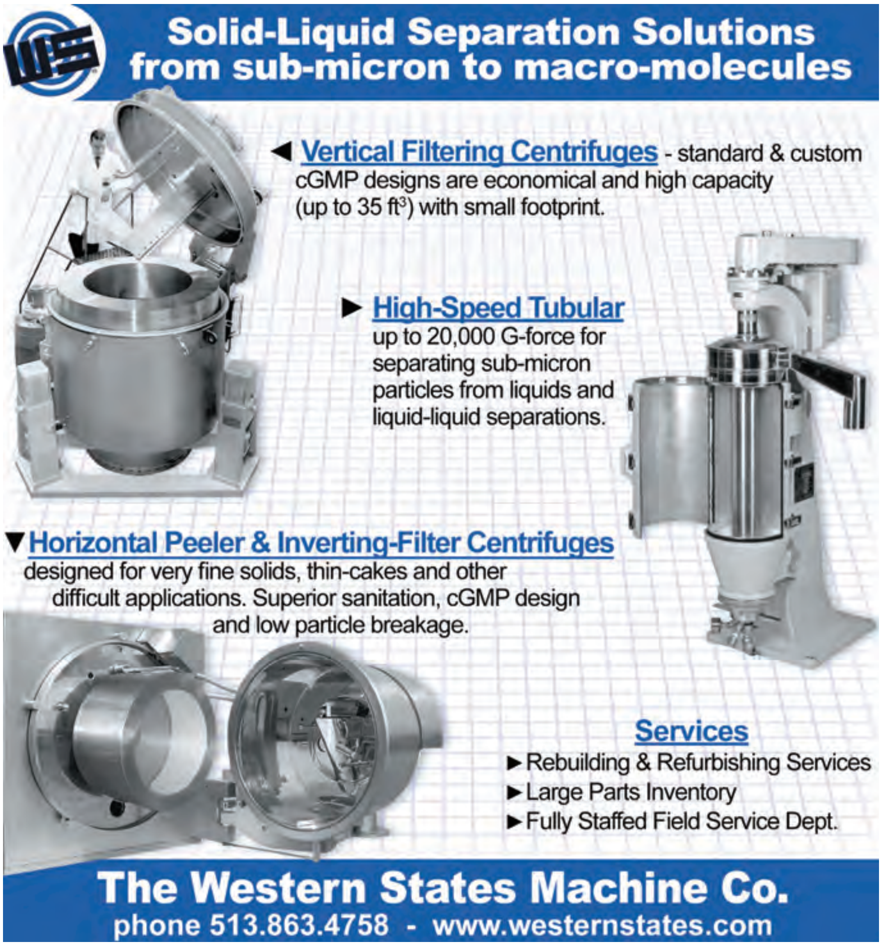
Wide-ranging enhancements to this design software

ChemCAD, an integrated suite of chemical process engineering software, features continuous improvements that evolve as industry changes. In the latest version of the software, engineers will find a licensing tool that expands the capabilities for computer licensing, as well as improved dynamic column performance and the capability for simultaneous heat- and mass-transfer models in distillation columns. The enhancements also include an improved user-defined component database that enables users to specify electrolyte density, viscosity, diffusivity, Henry's constants and more. The newest ChemCAD version also features a new operating mode that can help speed calculation for complex simulations. Booth 3306 — *Chemstations Inc., Houston*
www.chemstations.com

A heat exchanger designed for hot acids and corrosives

The newly available plate-and-frame heat exchanger is designed specifically for handling hot acids and corrosive chemicals. The unit offers a cost-effective and high-performing alternative to the shell-and-tube heat exchanger designs that have been typically used for corrosive applications. The fully welded exchanger has a tantalum-alloy surface coating for corrosion resistance, and a gasket-less design that raises efficiencies over those of shell-and-tube designs by a factor of between five and seven, the company says. Booth 3222 — *Tantaline Inc., Waltham, Mass.*
www.tantaline.com ■

Scott Jenkins

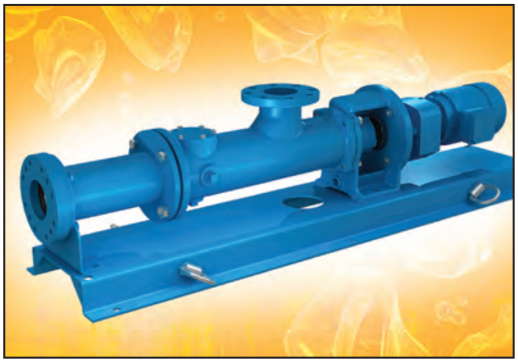


Flow Components International

Show Preview

weftec | 2011

the water quality event



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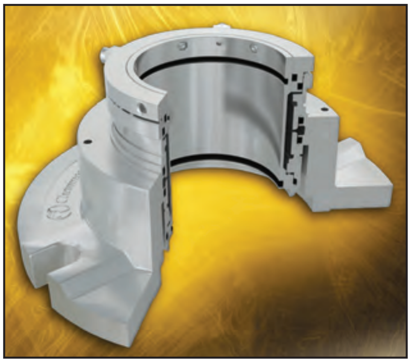


Chemineer

The 84th annual Water Environment Federation Technical Exhibition and Conference (Weftec 2011) will take place at the Los Angeles Convention Center from October 15–19 (the exhibition runs from October 17–19). The largest annual water quality event in the world will draw 18,000 attendees from 70 countries, according to event organizers.

The following descriptions represent some of the products that will be on display in the Weftec 2011 exhibit hall. For additional items, see the online version of this article at www.che.com.

Solvay Chemicals

Gas mass flowmeter designed for adaptability

The ST100 Series Thermal Mass Flowmeter (photo) is designed to be adapted to a wide range of new plant and process-control technology. Claimed to have the industry's most feature-rich and function-rich electronics, the ST100 was developed in response to process engineers' need for more comprehensive measurement information and for flexibility to adapt to plant technology that might be deployed in the future. The ST100 measures gas mass flowrate, total flow, temperature and pressure, and can store up to five unique calibration groups to accommodate broad flow ranges, differing mixtures of the same gas, and multiple gases. A removable 2-GB micro-SD memory card can store 21 million readings. Booth 5763 — *Flow Components International LLC, San Marcos, Calif.*
www.fluidcomponents.com

A compact close-coupled pump design

Specifically designed for lower-pressure, lower-flow applications, Model WA and WB pumps (photo) offer a compact, close-coupled configuration. The pumps are ideal for municipal sludge and applications that require the transfer of highly viscous fluids and solids where a close-coupled configuration is preferred, but the robustness of a gear joint is desired, the company says. Features of the WA pump include optimized rotor-stator geometry, sealed, gear-type universal joint drive train, and bearings integral to the adapter housing that support the radial thrust loads at the rotor-stator. The WB pump has similar features, except no shaft bearings and a traditional close-coupled design with thrust and radial loads supported by the bearings in the gear reducer. Booth 2211 — *Moyno Inc., Springfield, Ohio*
www.moyno.com

Disinfect wastewater without halogenated compounds

Environmentally compatible Proxitane WW-12 Peracetic Acid (PAA) microbiocide is used for biological control in municipal wastewaters (photo). This EPA-registered wastewater disinfectant is an alternative to halogenated disinfectants, such as chlorine-based chemicals, and can have a positive synergistic effect on an existing ultraviolet (UV) disinfection system by simply adding it into the wastewater. Compared to dosage requirements for industrial grade NaOCl, WW-12 is applied at a similar rate, but does not require a dechlorination step, or form chlorinated byproducts. Booth 8514 — *Solvay Chemicals Inc., Houston*
www.solvaychemicals.us

Change these seals quickly and easily

Specifically designed for agitators, ChemSeals (photo) employ this com-

Note: For more information, circle the 3-digit number on p. 70, or use the website designation.

Phoenix Contact USA

Watson-Marlow Pumps Group

pany's "swing-out" agitator seal-change design, which allows quick and easy replacement. ChemSeals feature high runout, reverse rotation and reverse-pressure capability, which keeps seal faces closed when tank pressure exceeds seal pressure. ChemSeals are available in a variety of materials, and can be easily retrofitted to existing agitators from this company. They come in standard sizes of 2.0, 2.5, 3.0 and 3.5 in., and can handle temperatures up to 356°F and pressures up to 300 psi. Booth 2310 — *Chemineer Inc., Dayton, Ohio*

www.chemineer.com

An industrial PC with a wide temperature range

The VL BPC Mini (photo) is a miniature, embedded, industrial box PC that can operate within a wide temperature range (–40 to 65°C). Part of the Valueline product series, the BPC Mini employs a fanless design in a compact package that is mountable on a DIN rail. It features Intel Atom Z510PT processors that are specially selected to reduce energy consumption and heat production. Designed for embedded operating systems, the computer also has high shock and vibration ratings, making it suitable for rugged applications. Booth 4653 — *Phoenix Contact USA, Middleton, Pa.*

www.phoenixcontact.com

Achieve greater reliability with this peristaltic pump

This peristaltic pump (photo) achieves accuracies of ±1% and greater reliability than diaphragm pumps. Designed for metering water-purification chemicals like $NaOCl$ and $FeCl_2$, the low-maintenance pump requires no back-pressure regulators or de-gassing valves. Booth 417 — *Watson-Marlow Pumps Group, Wilmington, Mass.*

www.wmpg.com ■

Scott Jenkins

WHO'S WHO


Griffiths


Heintzelman


Lipetzky


Harris


Park

Carbogen Amcis AG (Bubendorf, Switzerland), a pharmaceutical process developer and manufacturer of active pharmaceutical ingredients, names *Mark Griffiths* CEO.

GE Energy (Atlanta, Ga.), names *Dan Heintzelman* CEO of GE Oil & Gas. He is currently CEO of GE Energy Services, and will succeed Claudi Santiago, who is retiring in December.

Pete Lipetzky becomes general manager of the DuBois, Pa., facility of Magnet Applications, a subsidiary of **Bunting Magnetics** (Newton, Kan.).

Chuck Harris becomes vice president of midwest operations, distribution and fulfillment, based in Chicago, for **Intelligrated** (Cincinnati, Ohio), a provider of material-handling solutions. The company also names *Chris Arnold* vice president of operations and solutions development.

Kroff Chemical Co. (Pittsburgh, Pa.), a provider of chemicals and processes for water and wastewater treatment, names *Jim Skiba* senior account executive and *Daniel Gray* sales representative.

Deacom, Inc. (Wayne, Pa.), a producer of enterprise resource planning (ERP) software, promotes *Amanda Mackedanz* to vice president of sales.

Vertellus Specialties, Inc. (Indianapolis, Ind.), a specialty chemicals company, names *Bentley Park* president of the Vertellus Agriculture and Nutrition business unit. ■

Suzanne Shelley

Specifying Elastomer Seals for Plastic Piping

Careful attention to elastomer properties and variation by manufacturer can help optimize specification

Matt Tones, **Lou Mattina**
and **Jim Drago**
Garlock Sealing Technologies

TABLE 1. THE ACRONYM 'TAMPSS'	
Temperature	The temperature of the media contacting the seal (Figure 1). This will be higher for rotating equipment due to frictional heat
Application	Detailed information on the intended use of the material and the use of the equipment into which it will be installed, including the expected performance. Typical applications include flanges, oil seals, expansion joints, stoppers, hatches, covers, doors and liners
Media	Liquid, gas or solid media in contact with the elastomer during normal operation. For elastomeric materials, this is usually the first factor to consider as it narrows the scope of viable materials. Also important are any secondary media associated with cleaning and other activities apart from the primary process
Pressure	Internal system pressure, including periodic spikes or surges inherent in the service
Size	Overall dimensions, thickness and cross-sectional sizes
Speed	For rotating and reciprocating applications whose rates of movement are used in conjunction with dimensional data to calculate surface speeds

TABLE 2. COMMON ELASTOMERS AND USES

Elastomer type	Services
Ethylene propylene diene monomer (EPDM)	Water, steam, mild acid and base resistance
Butyl rubber	Water, mild acid and base resistance
Fluoroelastomer (FKM)	Excellent oil, solvent, acid and base resistance
Natural rubber	Water, mild acid and base resistance
Neoprene (CR)	Good oil, water and base resistance
Nitrile rubber (NBR)	Oil and fuels (aliphatic hydrocarbons)
Silicone	Excellent heat resistance and good oil resistance
Styrene butadiene rubber (SBR)	Water

The chemical process industries (CPI), like many others, increasingly employ non-metallic piping systems for fluid transfer — including polyvinyl chloride (PVC), chlorinated polyvinyl chloride (CPVC) and fiberglass-reinforced plastic (FRP) — instead of exotic metal piping. While non-metallic piping systems have benefits, such as lighter weight and easier installation, they pose a challenge with regard to selecting gaskets, which typically have been polytetrafluoroethylene (PTFE)-based.

The challenge stems largely from the fact that elastomer compounds may have significant differences even if they share the same generic nomenclature. Indeed, there can be significant variations within the same types and grades of elastomers from different suppliers. By simply specifying neoprene (chloroprene rubber) or EPDM (ethylene propylene diene monomer), for example, engineers may not arrive at the right elastomer seal for the intended application. Therefore, in specifying elastomer seals for CPI applications, engineers need to exercise due diligence both in how they approach relationships with elastomer suppliers and in the information they seek about elastomer properties.

In the specification and purchasing process, it is important to establish relationships with suppliers that are conducive to collaboration. It is also crucial to undertake a thorough review of the available information on elastomer types and their properties. Combining these approaches will greatly reduce the risk of using the wrong material for an application, and help guard against chemical spills, employee injury and facility downtime.

Collecting key information

The majority of non-metallic piping systems require the low seating stress of softer, more compressible elastomeric or rubber gaskets. When specifying elastomers for sealing applications, most users rely on three principal criteria: polymer type, price and hardness. However, to assure optimal performance and longevity of service, additional detailed information is required on the material's intended use and the conditions under which it will need to function. Further, selecting an elastomer seal without a complete understanding of the manufacturer's terminology can lead to selection of the wrong material for an application.

To arrive at the best elastomer for a particular sealing application, begin by defining the application in terms of the material's compatibility with the media being sealed, as well as the required grade and compressibility. A

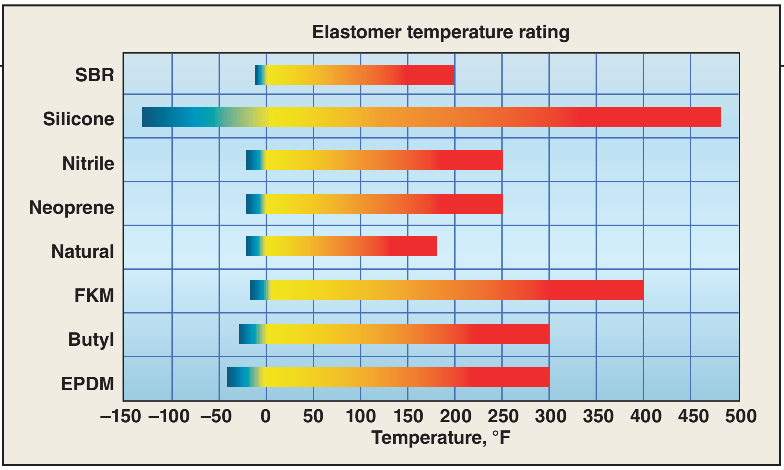


FIGURE 1. Temperature resistance is a critical parameter for elastomer selection. The temperature resistance ranges of the common elastomers listed in Table 2 are compared

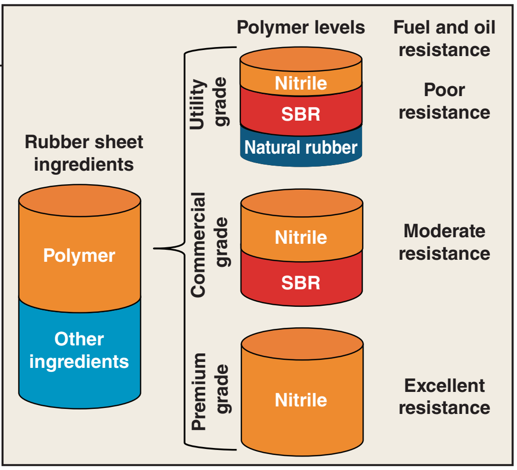


FIGURE 2. Elastomer makeup differs by grade, with significant impact on chemical resistance. In this case, nitrile content affects resistance to petroleum

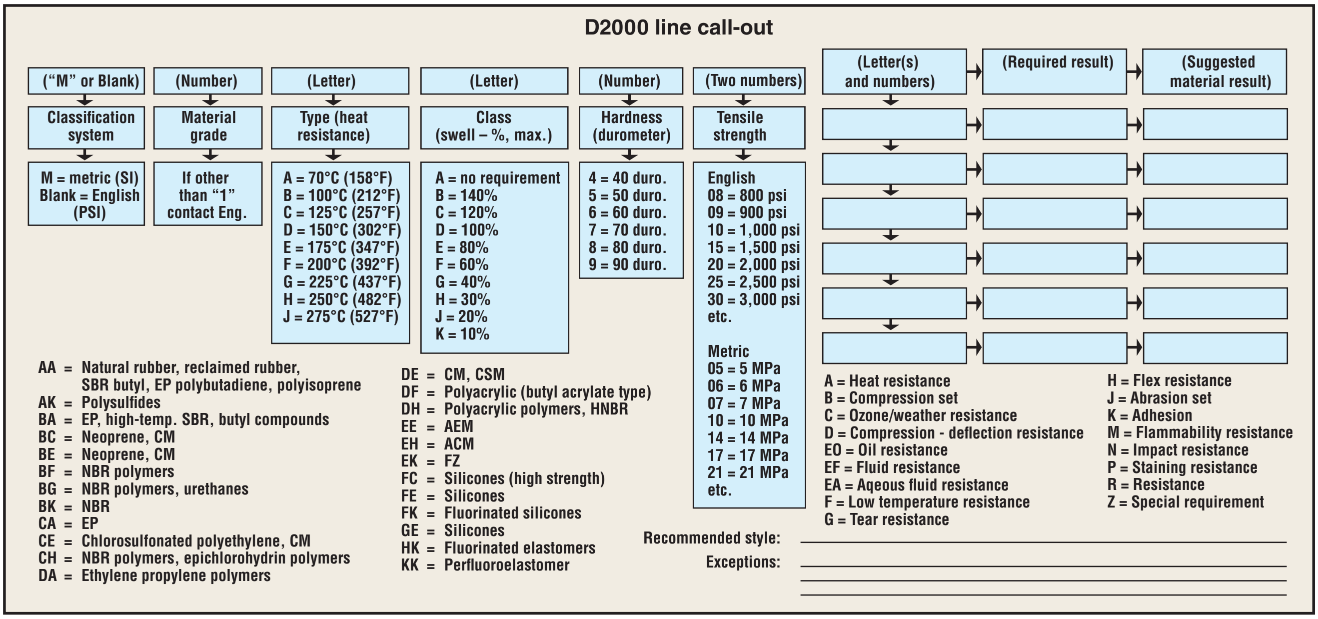


FIGURE 3. The ASTM D2000 Line Callout system for elastomers is like a vehicle identification number for automobiles

TABLE 3. CORRESPONDING ELASTOMER SHEET GASKET PROPERTIES

Compressed fiber and PTFE	Elastomer
Temperature	Same as PTFE and compressed fiber
Pressure	Same as PTFE and compressed fiber
Pressure × temperature rating	Same as PTFE and compressed fiber
Sealability	Unpublished; rubber sheet leakage is not detectable with standard test methods
Creep relaxation	Compression set
Compressibility	Hardness expressed as Shore A Durometer points
Recovery	Unpublished; rubber is completely elastic at room temperature

simple acronym, TAMPSS (temperature, application, media, pressure, size, speed) can be helpful in identifying the pertinent information (Table 1).

Elastomer components

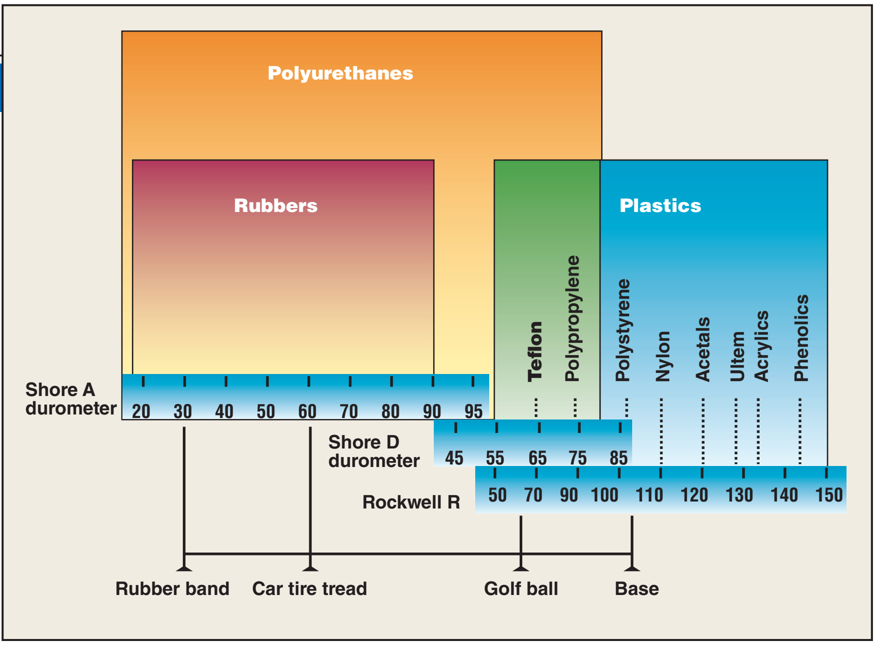
In and of themselves, elastomeric polymers are not suitable for industrial applications, but they are necessary to render finished products elastic. Table 2 lists several common elastomers along with the typical services for which they are used. Among the most common are nitrile butadiene rubber (NBR), polychloroprene (Neoprene) and fluoroelastomer (FKM, Viton*).

Finished elastomer products are the combination of a number of various ingredients, though they are identified by the primary polymer used. In addition to the primary long-chain polymers from which they derive their names, elastomers also contain other materials and various additives to promote curing and desired properties. An elastomer compound is basically a recipe for blending the ingredients it contains. These compounds typically include inorganic clay and carbon black fillers, pigments, plasticizers and processing aids that produce the requisite chemical reactions to yield a useable material. Blended into a uniform, uncured mixture, these ingredients stabilize the finished elastomer for conformance to specifications for hardness, tensile and tear strength, elasticity, compression and creep. This "green" mixture is heated, milled, calendered, extruded or molded into sheet form or functional shapes.

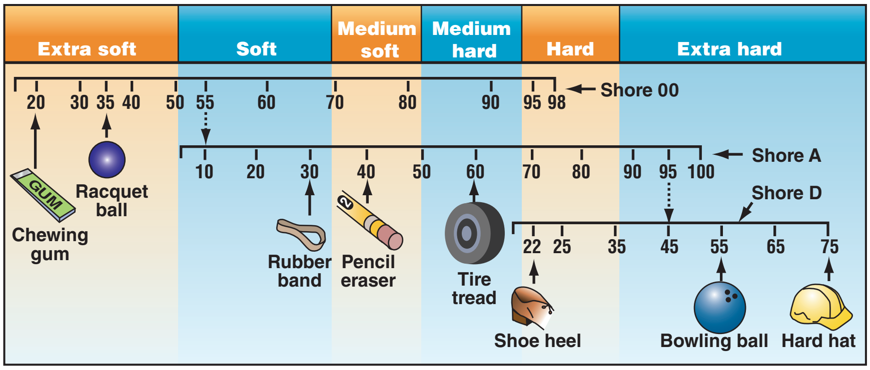
Elastomers are generally classified into three grades: utility, commercial and premium. Because there are no

*Viton is a registered trademark of Dupont Performance Polymers

FIGURE 4. Shore Durometers can be used to evaluate rubber hardness



FIGURES 5 AND 6. Material hardness of various plastic and rubber compounds fall onto different Shore scales



industry standards with regard to formulation, products can vary significantly from one manufacturer to another. A product's chemical resistance is largely determined by its polymer content. Figure 2 illustrates how the polymer content, in this case nitrile, can affect the material's fuel and oil resistance.

Notwithstanding these variations, users can take a deliberate approach to assuring that they are purchasing the elastomer that meets the needs of each application. First and foremost, end-users should have an open discussion with suppliers regarding the details of the process application, including intended service, desired performance and viable materials. This discussion should then be supplemented by research on the relevant decision-support data.

Rubber classification tool

Given manufacturers' substantial investments in proprietary formulations, it is highly unlikely that consistent, industry-wide standards for elastomers will ever be developed. This poses a quandary for users seeking suitable materials for their applications. However, the standard ASTM D2000-08, "Standard Classification System for Rubber Products in Automotive Applications" can be applicable and useful to the CPI, despite its somewhat misleading title.

The developers of the standard explain that the purpose of the classification system set forth in ASTM D2000 is to provide guidance to the engineer in the selection of practical, commercially available rubber materials. The scope of ASTM D2000 says, "This classification system is based on the premise that the properties of all rubber products can be arranged into characteristic material designations. These designations are determined by types, based on resistance to heat aging, and classes, based on resistance to swelling in oil. Basic levels are thus established, which, together with values describing additional requirements, permit complete description of the quality of all elastomeric materials."

Another significant purpose of ASTM D2000 is to provide a method for specifying these materials by the use of a simple "line call-out" designation. ASTM D2000 line call-outs for elastomers are like the vehicle identification number on a car. Alphanumeric designations divulge information about the product, including up to 23 categories, by material type and performance properties. Figure 3 shows the overall organization of the line call-outs. The first six positions in the numbering scheme provide basic information. The first indicates whether the data are expressed in Metric SI or English units. The second identifies the material grade, which is important in the overall cipher of the code, since it establishes the level of performance the material must meet.

The third and fourth positions assign a letter pair indicating the material's heat resistance and swell-in-oil characteristic, respectively. Both are critical to the specification. The material's ability to maintain its properties under these conditions will dictate the need for a premium-, commercial- or utility-grade product. These letter pairs direct the user to the tables that comprise over 80% of the content of the ASTM D2000 standard. The tabulations are contained in Table 6 of the standard (Basic and Supplementary Requirements for Classification of Elastomeric Materials). A dedicated table for each letter pair (for example, AA, BC, BK, CH, and so on) provides the properties of the material.

The fifth position of the line call-out code designates the hardness,

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****Editor's note**: The Shore scale refers to an instrument, the durometer, developed by Alfred F. Shore, for measuring hardness in plastics and rubbers. The inventor's name has come to be used for the measurement, as well as the instrument.

TABLE 4. ORGANIZATIONS AND STANDARDS ADDRESSING ELASTOMER CHEMICAL COMPATIBILITY

Organization	Title	Description
National Association of Corrosion Engineers (NACE)	Standard TM0196-96, "Standard Test Method, Chemical Resistance of Polymeric Materials by Periodic Evaluation"	This standard defines procedures for conducting chemical compatibility tests by immersing material samples in test media and measuring key attributes, such as hardness, tensile strength and weight. In addition to the test method, it offers guidance on the analysis of data for decision support.
Materials Technology Institute of the Chemical Process Industries (MTI)	Report R-17, "Guide to Elastomer Testing for Chemical Resistance"	Developed by and for those in the chemical process industries, the report provides guidance on test parameters, control and origin of test materials, coupon property change tests versus application attributes testing and acceptance criteria. The tables cover root causes of observed media effects, test methods to gauge key performance properties and a method of quantifying performance of a multi-attribute evaluation.
International Standards Organization (ISO)	TR 7620, "Rubber materials — Chemical resistance"	This standard offers a compilation of chemical resistance rankings from a wide variety of sources, all documented in the reference column of an extensive table listing compatibility of over 400 fluid media. It offers an explanation of its classification and ranking system and guidance to evaluate the suitability of elastomeric materials.

expressed as Shore A–Scale points,** (Figures 5 and 6) and the sixth position designates tensile strength. Supplementing this basic line-call-out information are more than 17 different categories of properties, such as heat, fluid, tear and abrasion resistance. These properties are designated with alphanumeric codes ciphered in Table 6 of the standard. Figure 3 contains the full list.

Using line call-outs

When using the line call-out system in specifying elastomers for seals, there are a few "rules of thumb" that can greatly help. Here are three of the most widely useful:

1. The longer the call-out, the higher the quality of the material (a long number indicates extensive specification and testing)
2. Low tensile strength indicates low polymer and high filler content
3. High elasticity indicates high polymer content, lower filler content and higher tensile strength

The alpha pair of positions three and four indicate polymer type. Users rarely develop their own line call-outs, but rather work with their suppliers and the TAMPSS guidelines to select a suitable material appropriate for their particular application.

Once the selection is made, the manufacturer supplies the ASTM D2000 line call-out specifying the material generically and excluding substandard materials. Specifying tensile strength alone, for example, will eliminate low-polymer-content, utility-grade materials. Specifying oil swell will eliminate grades that contain a range of unnamed and incompatible polymers. Special resistance to specific media can be added as a special "Z" requirement.

The properties of elastomer sheet gaskets are not always expressed in the same terms as those for compressed-fiber and PTFE-sheet gaskets. Table 3 shows the corresponding properties for elastomer sheet gaskets.

Elastomer compatibility

Media compatibility is a key determinant of an elastomer's suitability for an application. There are a number of independent sources providing information on the chemical compatibility of elastomers. Manufacturers offer tabulated information with "acceptable-depends-unacceptable" performance rankings. Unless stated, these do not take into account elevated temperatures, which can exacerbate the effects of a chemical. Nor do these tables reflect the application. For example, an elastomer used to line a vessel has far more exposure to service conditions than a rubber gasket in a flange. The best approach to selecting the optimal elastomer for a given application is to refer to the published literature and consult with the manufacturer's application engineers. Table 4 shows independent sources of information on the chemical compatibility of elastomers. ■

Edited by Scott Jenkins

Further reading

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2. "Guidelines for Hazard Evaluation Procedures — With Worked Examples (2nd Ed.)," Center for Chemical Process Safety/AIChE, 1992.
3. American Specialty Equipment, Inc., Process Safety Management Guidelines for Compliance, OSHA document 3133, 1994 Appendix., copyright 1999 – 2005, www.exforklifts.com.
4. American Petroleum Institute (API) "Recommended Practice 521, Guide for Pressure-Relieving and Depressuring Systems", 4th ed. March 1997; (www.api.org).
5. 29 CFR 1910.119 "Process Safety Management of Highly Hazardous Chemicals," OSHA, Washington, D.C., 1992.
6. "Plant Guidelines for Technical Management of Chemical Process Safety (Revised Edition)," Center for Chemical Process Safety/AIChE, 1992, 1995.

Authors

Matt Tones is director of product management in North America at Garlock Sealing Technologies (1666 Division Street, Palmyra, NY 14522; Email: matt.tones@garlock.com; Phone: 800-448-6688) and has more than ten years of experience with the company. Prior to his present position, Tones was manager of applications engineering, training and customer support. He also has served as product manager for the company's line of restructured PTFE gaskets, and as liaison with OEM customers. He began his career in Garlock's testing laboratories.

Lou Mattina is manager of elastomeric materials at Garlock Sealing Technologies (Email: lou.mattina@garlock.com). He has more than 30 years of experience in the rubber business, including compounding, mixing, calendaring, extruding, and injection, compression and transfer molding. Among the products he has helped to develop are NSF materials for potable water, abrasion-resistant compounds, FDA formulations, and fire-, heat- and ozone-resistant compounds. He is a member of the American Chemical Society Rubber Division, Energy Rubber group and American Waterworks Association.

Jim Drago is manager of business development and integration at Garlock (Email: jim.drago@garlock.com). He has worked in sealing technology for more than 25 years with experience in engineering, applications, product development and management. He has authored numerous articles on sealing to meet fugitive emission regulations, presented papers at technical symposiums and contributed to the formulation of industry standards and guides for Application Programming Interface (API), American Society of Mechanical Engineers (ASME), Electric Power Research Institute (EPRI), and Society of Tribologists and Lubrication Engineers (STLE). He is a certified professional engineer.

Moving Air In Pneumatic Conveying Systems

These selection criteria apply to dilute-phase systems

Amrit Agarwal
Pneumatic Conveying Consulting

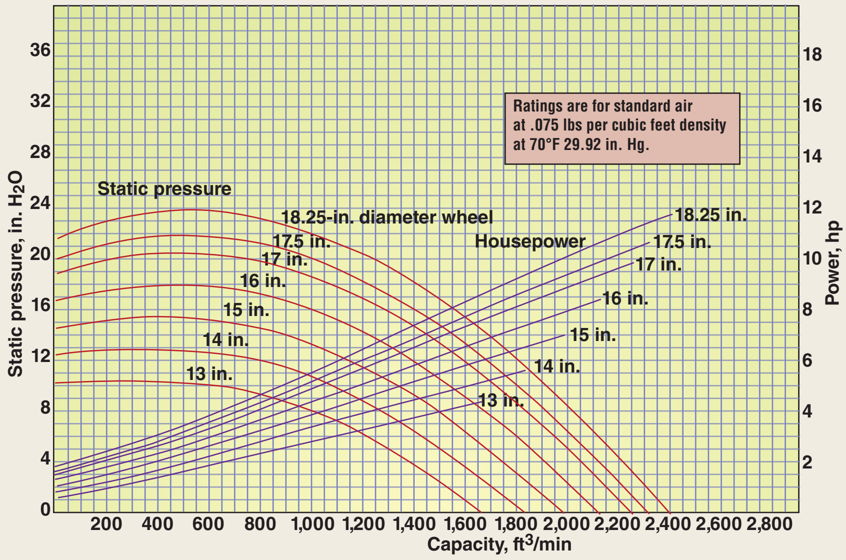
Dilute-phase conveying systems generally use centrifugal fans and positive displacement blowers for supplying conveying air to the conveying system. However, for some conveying systems, compressed air from a central compressor station is also used. The two important criteria required for pneumatic conveying are air flow and air delivery pressure. Different air movers have different characteristics in the relationship between these two important criteria. Selection of an air mover is based on this relationship.

FANS

Fans are generally used for low-pressure conveying systems where the conveying pressure is less than 2 psig or where both low pressures and large air flows are required. Fans that are used in these cases are mostly of the centrifugal type. Their main disadvantage is a relatively steep sloping performance curve, wherein even a small change in discharge pressure results in a significant change in air volume delivered.

Fans operate by imparting movement to air as it passes though the unit. The kinetic energy of the moving air is converted into static pressure when the airflow is restricted. A fan's volumetric output depends upon its discharge pressure. This output decreases as the pressure increases and increases as the pressure decreases. Because of this inverse relationship and a sharp sloping performance curve, fans are not positive displacement machines, and their output air volume changes with a change in discharge pressure.

The best application of fans is a system in which conveying conditions (such as conveying rate, distance and material type) are relatively constant parameters, and the resulting conveying system pressure is not expected to change much. Figure 1 shows typical performance curves for fans with different sizes of impeller diameters. The table in this figure gives air flows at various static pressures and the resulting motor horsepower.



HORSEPOWER VERSUS STATIC PRESSURE AND AIR FLOW FOR FOR A 3,500 RPM FAN

Capacity, cfm	18.25-in. wheel		17.0-in. wheel		15.0-in. wheel		13.0-in. wheel	
	SP	BHP	SP	BHP	SP	BHP	SP	BHP.
400	23.5	3.0	20.3	2.6	15.1	1.9	10.2	1.3
500	23.6	3.4	20.4	2.9	15.2	2.2	10.1	1.5
600	23.5	3.7	20.3	3.3	15.1	2.5	10.0	1.7
700	23.3	4.2	20.1	3.7	14.9	2.9	9.7	2.0
800	23.0	4.6	19.8	4.0	14.5	3.2	9.2	2.3
900	22.5	5.0	19.3	4.5	14.0	3.5	8.7	2.6
1,000	22.0	5.5	18.6	4.9	13.3	3.8	8.0	2.8
1,100	21.0	6.0	17.7	5.3	12.3	4.2	7.1	3.1
1,300	19.0	6.9	15.8	6.1	10.4	4.9	5.0	3.5
1,500	16.7	7.9	13.3	6.9	7.9	5.5	2.4	4.0

FIGURE 1. Here are typical performance curves for fans with various impeller diameters. The table below the figure gives air flows at various static pressures (SP) and the resulting motor horsepower (brake horsepower; BHP)

Operating characteristics

1. Airflow reduces as air pressure increases. Air flow stops when the conveying line plugs.
2. Horsepower reduces as air pressure increases.

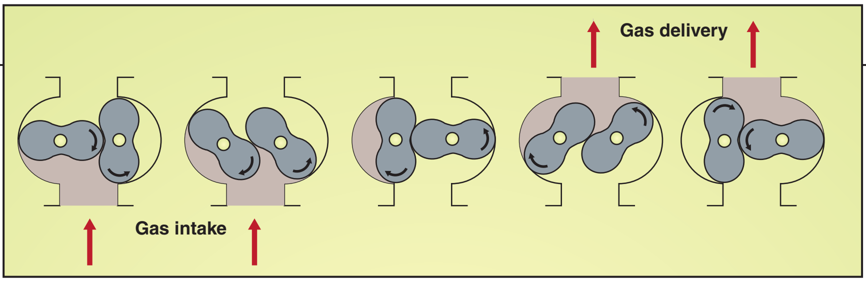


FIGURE 2. Blowers have two rotors that are mounted on two parallel shafts within the blower housing. As the two rotors rotate in opposite directions, air is drawn into the space between the two rotors and the housing wall. This air is trapped between the rotors and the housing, and is transferred from the blower inlet to the blower outlet without compression

3. Fans are unloaded by closing either the inlet or the outlet port.
4. Fans are mostly used in applications that require high air volume at low pressures.

Advantages of fans

- Low cost
- No close clearances
- Relatively low noise level

BLOWERS

Blowers for dilute-phase pneumatic conveying systems are generally rotary, positive displacement, lobe type blowers. They deliver oil-free air at pressures up to 18 psig.

Figure 2 shows the operating principle of these blowers. The blower has two rotors that are mounted on two parallel shafts within the blower housing. These rotors rotate in opposite directions, and as they rotate, air is drawn into the space between them and the housing wall. This air is trapped between the rotors and the housing, and with rotation of the rotors the air is transferred from the blower inlet to the blower outlet without compression. This trapped air flows into the conveying line. If the conveying line air pressure is higher than the blower suction pressure, this trapped air mixes with the conveying line air and gets compressed to the conveying air pressure. These blowers do not generate any pressure. However, they withstand the pressure in the conveying line up to their pressure rating.

The position of the two rotors relative to each other is maintained by timing gears installed on the two shafts in a separate housing. This allows operation of the rotors without any lubrication.

These blowers are called positive displacement type because they deliver a constant volumetric air flow regardless of the discharge pressure. There is a small leakage flow (about 1–2%) called "slip" from rotor outlet to rotor inlet because of the narrow clearances between the rotors and the casing.

Compression ratio of these blowers is about 2 to 1, which means that if the inlet air is at 14.7 psia pressure, blower can handle discharge pressures up to two times 14.7 psia, or about 15 psig. With special timing gear design, some vendors can increase this rating to 18 psig. Vacuum rating of these blowers is in the range of 15 in. Hg, but with special designs, it can increase to 18 in. Hg.

Volumetric capacity of these blowers is from very small to very large. Capacity is directly related to blower speed. Figure 3 shows the relationship between flow, pressure and horsepower.

Maximum speed of the blowers has an upper limit because of the maximum allowable tip speed of about 4,500 ft/min of the timing gears.

Sizing and selection

The various steps in sizing and selecting a blower for a conveying system are given below:

Blower volumetric flow: From the pneumatic-conveying-system calculations, determine the actual cubic feet per minute (ACFM) of the air that is required to convey the solids. This flow will be equal to the conveying velocity (ft/min) multiplied by the cross-sectional area of the pipe (ft^2) at the pick-up point.

For pressure-type systems, calculate the volumetric flowrate of air that is lost through rotary valves. Estimate any loss of air through pipeline components, such as diverter valves, flexible hoses, pipe couplings an so on.

Add these losses to the conveying air flow. Add to this the blower slip flow. Calculate blower slip flow using vendor data and add this flow to the conveying air flow. This will give the total volumetric flowrate of air at the blower inlet. Use this flow for sizing the blower.

For vacuum type conveying systems, find out the total leakage into the conveying line (from rotary valves, diverter valves, flexible hoses, pipe line joints, and so on) and add this leakage to the calculated volumetric flow required for conveying. Then add to it the blower slip flow from outlet to inlet. Use this result to size the blower.

Conveying system design pressure: Use the following factors to determine the maximum design pressure for the conveying system:

- Pressure rating of the conveying blower
- Set point of the blower pressure safety valve (PSV) that protects the blower against over-pressure
- Pressure variations during actual operation of the conveying system
- Allowance for use of any empirical data in the calculations

Pressure rating of the blowers is generally 15 psig. Blower safety valve is then set at 15 psig.

Pressure drop in a conveying system can vary due to various reasons and can be assumed to be at least ±10% in a well-designed system. On this basis, the maximum design pressure will then be 0.9 × 15.0 = 13.5 psig.

To prevent the PSV from popping open due to pressure excursions, the setpoint of the PSV should be 13.5 psig. Conveying-system design pressure will be 10% below the PSV setting. This pressure will then be = 0.9 × 13.5 = 12.15 psig.

Use a 10% allowance for any errors in the data that is used in the calculations. With this allowance, the maximum design pressure comes to 0.9 × 12.15, or about 11 psig. On the above basis, conveying system design pressure should not exceed 11 psig.

Blowers are normally selected so that they operate at about the mid-point of their performance curves. Therefore, for a 15-psig maximum rating, the operating pressure should be about 7.5 psig. This gives a pressure drop range of 7.5 to 11 psi for the design of the conveying system. A lower pressure will require a larger diameter pipeline and a smaller blower. A higher pressure will require a smaller diameter pipeline and a larger blower. A good approach is to design a system about midway between these two options.

Blower discharge pressure (pressure-type conveying systems): From the pneumatic conveying calculations, determine the pressure drop in the conveying line. Then calculate the pressure drop for the flow of air in the pipeline between the blower and the solids' pick-up point. Determine the pressure drop in all blower accessories, such as air filters, silencers and coolers. Then determine the pressure drop at the end of the conveying line such as in bin vent filters and dust collectors, and add it to the conveying line pressure drop. This will give the total pressure at blower discharge (P_2).

Blower inlet pressure and temperature: Blower inlet pressure (P_1) will be the sum of the ambient pressure and pressure drops in equipment such as blower inlet filter and blower inlet silencer. From ambient conditions, find out the ambient pressure and ambient temperature (t_1, °C).

Required volumetric flowrate at blower inlet: Assuming adiabatic compression, calculate the volumetric flowrate of air (or gas) at the blower inlet (V_1), as follows:

$$V_1 = V_2\left(\frac{P_2}{P_1}\right)^{\frac{1}{K}} \qquad (1)$$

Where:

K = Ratio of specific heats at constant pressure and volume (C_p/C_v) for conveying air or gas (1.4 for air)

V_2= Volumetric flowrate of air required by the conveying system (volumetric air flow at blower outlet)

P_2 = Blower discharge pressure, psia

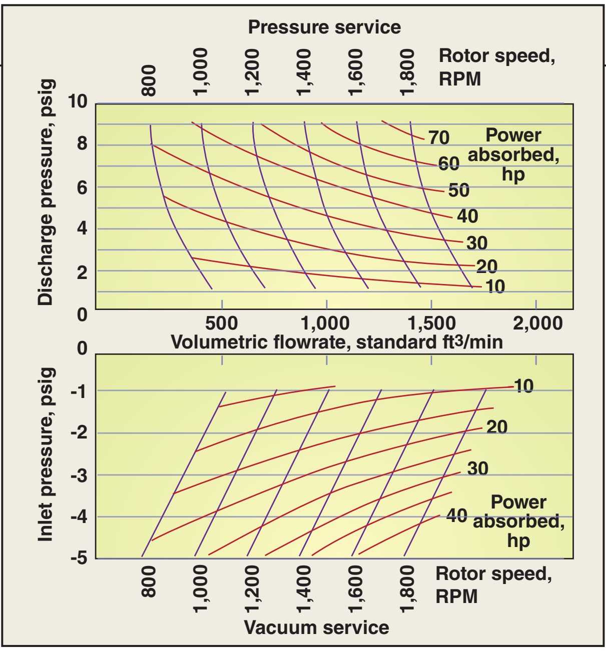
P_1 = Blower inlet pressure, psia

Note: In Equation (1), the value of V_1 is derived from conveying system calculations, not from an actual blower size based on its manufacturing data. Since blowers are made in different sizes, use vendor data to find a blower whose inlet volumetric flow in cubic feet per revolution (CFR) multiplied by blower speed in revolutions per minute (N, rpm) comes closest to the blower inlet volume, V$_1$, calculated in Equation (1).

$$V_1 \text{ (based on actual blower size, ft}^3\text{/min)} = CFR \times N \qquad (2)$$

Use this value of V_1 in Equation (3).

FIGURE 3. Blower capacity is directly related to blower speed. This graph illustrates the relationship between flow, pressure and horsepower



Blower horsepower (HP): Calculate the blower horsepower as follows. First, find out the gas horsepower (GHP):

$$GHP = \frac{(P_1V_1)\left(\frac{K}{K-1}\right)\left[\left(\frac{P_2}{P_1}\right)^{\frac{K-1}{K}} - 1\right]}{33,000} \qquad (2)$$

Where:

P_1 and P_2 are in lb/ft^2

V_1 is in ft^3/min [from Equation (2) not Equation (1)]

To determine the value of motor horsepower, the value of GHP is increased by the following allowances:

1. Conveying system pressure fluctuations of ±10% during operation. These can increase the motor load by 10%
2. An allowance of 10% for use of any empirical data in conveying system calculations
3. The resulting brake horsepower (bhp) is rounded off to match the hp rating of an available motor. This will give the blower motor horsepower .

Blower discharge temperature (t_2): Assuming adiabatic compression, blower discharge temperature is determined as follows:

$$T_2 = (273 + t_1)\left[\left(\frac{P_2}{P_1}\right)^{\frac{K-1}{K}} - 1\right] \qquad (4)$$

Where:

T_2 = Blower discharge temperature, degrees Kelvin

t_1 = Blower inlet temperature, °C

t_2 = Blower discharge temperature, °C

P_2 = Blower discharge pressure, psia

P_1 = Blower suction pressure, psia

K = Ratio of specific heats (1.4 for air)

$t_2 = T_2 - 273$, °C (5)

(t is in degrees C, T is in Kelvin)

Blower selection: Use manufacturers' catalogs to find a blower that will meet the above requirements of flow and pressure (Figure 4).

Consider the following example:

- Let the inlet flow (V_1) = 2,321 cfm, at blower suction conditions.
- Let the blower discharge pressure (P_2) = 12 psig.

Then, using the catalog for a Roots blower, select the blower with designation "Frame 1212 RAS Whispair" (Figure 4).

In this curve, draw a horizontal line from between 2,321 cfm, and the curve for 12 psi. From the intersection point at 12 psi, go vertically down to the blower speed line. Blower speed comes to 1,175 rpm and motor horsepower comes to 150 hp.

Blower drive motor: Determine the setting of the safety valve at the blower discharge. This should be 10–15% above the maximum operating pressure. In the blower curve, read the horsepower at the higher discharge pressure (safety valve setting). Select motor horsepower accordingly.

Typical drive methods for blowers:

- For blowers up to 200 hp, use V belt drives
- For blowers from 200 to 400 hp, use a gear reducer
- For blowers above 400 hp, use direct drive

Note: Use manufacturer's recommendation in all cases.

Blower noise level: Silencers will be required to reduce blower's noise level. A noise level of 85 dbA is possible with

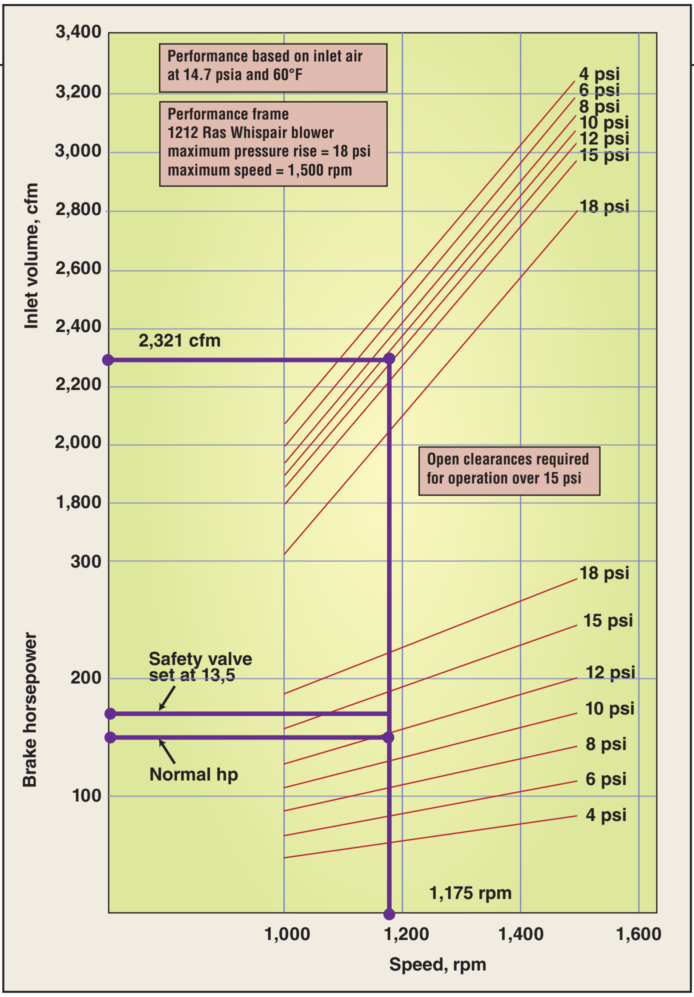


FIGURE 4. Once the required blower inlet volume (V_1) is calculated in Equation (1), use vendor data to find a blower whose inlet volumetric flow [from Equation (3)] comes closest to the blower inlet volume, V_1, calculated in Equation (1)

well-designed silencers but full acoustic enclosures around the blower are required to achieve 80 dbA.

Major blower selection criteria

Major criteria for blower selection are given below.

1. ***Positive displacement:*** Blower is to be positive displacement, twin lobe type. Three lobes can be used as an option.
2. ***Oil free:*** Blower is to be oil free type. In other words, oil used to lubricate the gears should not enter the rotor housing.
3. ***Operate at middle of operating range:*** Blower selected should operate close to the middle of its operating range. Always obtain the blower performance curve from its vendor. This curve will show volumetric flow versus blower pressure at various blower speeds.
4. ***Optimum speed:*** The blower should operate at about 1,800 rpm.
5. ***Aim for high volumetric efficiency:*** Use the highest possible volumetric efficiency (lowest slip) by selecting a blower with minimum clearances between the rotors and the housing.
6. ***Aim for high mechanical efficiency:*** Select a drive that has high mechanical efficiency.
7. ***Low pressure-drop inlet filter:*** Inlet filter should be of the low pressure-drop type (less than 1 in. H_2O) and should be easily replaceable.
8. ***Materials of construction and lubrication:*** The standard materials of construction are cast and forged steel. Bearings are lubricated either by slinger rings or with forced lubrication. Shaft seals are usually labyrinth or piston ring type with lip-type oil seals.
9. ***Package details:*** Blowers usually are bought as a package including blower, drive motor, silencers and filters. For sizes under 200 hp use a belt drive because it permits easy speed changes if needed. Sizes over 200 hp are usually gear driven. Larger sizes are generally driven directly from a drive motor but this method prevents blower speed change if found necessary. Blowers are inherently very noisy; therefore, silencers are generally required to meet acceptable noise standards. Even with the silencers, the noise level may still be high, and additional acoustical protection, such as sound enclosures, may be required.
10. ***Inlet filters are installed on the inlet or suction line of pressure blowers to keep atmospheric dust or other air-borne materials out of the process and from getting into the blower.*** On vacuum systems, the inlet filter is installed at the beginning of the conveying line upstream of the solids injection point. The better quality inlet filters are pleated polyester or polyethylene felt backed by stainless steel wire mesh for support and designed for easy cleaning and reuse. Some filters are pleated paper similar to an automobile air cleaner, and others are loose fiberglass in sheet metal housing similar to household furnace filters. These are the "throw-away" kind of filters. Although any of these materials are acceptable in this service, the pleated felt is preferred because it removes nearly all particles under a few microns in size.

   Inlet filters are sized for an air to filter ratio between 30:1 to 50:1 based on actual cfm of air per square foot of filter area. The pressure drop across the filter should be less than 1 in. H_2O.
11. ***In-line filters:*** Sometimes, an in-line filter is used in the blower discharge line before the solids feed point to remove any pipe scale or rust from entering the conveying line. Another approach to in-line filtration is to use a non-scaling or non-rusting material of construction such as stainless steel, or aluminum for the filter housing and the silencers.

    In-line filters are usually "cord-wound" cones, felt cones or pleated felt. The filter elements are enclosed in a cylindrical vessel with a pressure rating compatible with the maximum blower pressure. The filter elements are usually the disposable type and are sized on the same basis as the inlet filters — that is between 30:1 and 50:1 of air-to-media area ratio.
12. ***Air coolers:*** Air coolers are required in most pressure type conveying systems when the blower discharge temperature is 80*C or above. Some materials, such as plastics, are heat sensitive and

generate more fines and dust at high temperatures.

Air coolers used in conveying systems are of a standard design. They are usually constructed of several "banks" of finned copper tubes that are very similar to an automobile radiator enclosed in aluminum or stainless steel housing. Both air-cooled and water-cooled exchangers are acceptable. However, use a low-pressure drop cooler such as a straight flow type.

In some operating situations, such as relatively low cooling-water temperature and warm, moist air, water may condense on the air-side of the cooler. The air velocity on the shell side of the cooler is low enough to de-entrain this condensed water and allow it to collect at the low point of the cooler shell. Where this is likely to occur, the cooler should be placed in a horizontal run of pipe and a drain valve provided at the low point of the shell. An automatic drain should be provided if the problem is severe.

Blower instrumentation

The following instrumentation and controls are necessary for troublefree operation of th conveying system:

- A pressure gage and a pressure transmitter at the blower discharge to monitor blower operating pressure and to automatically shut down the solids feed if pressure becomes too high
- A temperature gage at the blower discharge to monitor blower discharge temperature

COMPRESSORS

Compressors are required for high-pressure pneumatic conveying, such as dense phase conveying. Dedicated compressors are not used for dilute phase conveying because their high pressures are not required for these systems. However, if a central compressed air system is available, and the cost of compressed air can be justified, this air can be used for dilute-phase conveying systems. To use this compressed air, use a pressure control valve to reduce the conveying pressure and a flow control valve to regulate the air flow. ■

Edited by Rebekkah Marshall

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REBOILER CONDENSATE DRUMS:

Silencing Hydraulic Hammer

While condensate pots are widely used, there is still much to be learned to avoid operational problems

Henry Kister,
Fluor Corp.

Antonio João Dias Prestes
and **Luiza Milbroth Jorge**,
Braskem S.A.

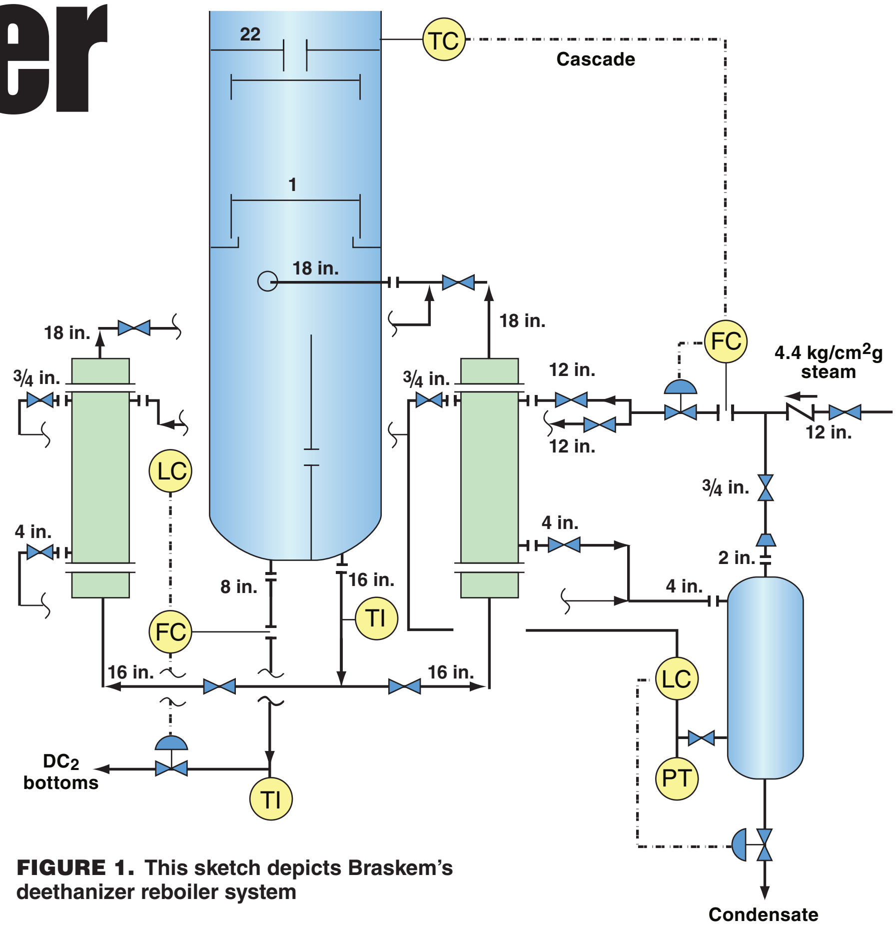

FIGURE 1. This sketch depicts Braskem's deethanizer reboiler system

Condensate pots are commonly used on the condensing sides of some reboilers, such as those that are heated by steam or refrigerant vapor. These pots provide a liquid seal that prevents uncondensed vapor from blowing out of the reboiler into the condensate system. A break in this seal can result in heat transfer losses. With steam reboilers, blowing vapor into the condensate header may also lead to hammering. Hammering may also be caused by poor design of the condensate pot.

Hammering is the problem described here. Braskem's deethanizer reboiler-condensate drum experienced hydraulic hammering when the reboiler operated at low steam loads and when the column loads were reduced quickly. The condensate-drum level indicator was unreliable and insensitive to the variations in level-control-valve opening. Condensate-drum level control was poor, and the control valve had to be operated on manual.

This article explains the troubleshooting process and subsequent modifications made to solve the problem. Lessons learned are that correct, inexpensive hydraulic design of a condensate pot is central to stable, trouble-free reboiler operation; and that contrary to recently published reports, correctly locating the condensate inlet to the drum is central to trouble-free operation.

Background

Reboilers that are heated by latent heat (such as by steam or refrigerant vapor as mentioned above) often use condensate pots to provide liquid seals. When a reboiler seal is broken, vapor may channel through the reboiler and heat transfer is lost as described in case studies found in Refs. 1–3. Good practices for design of condensate drums have been described in a classic paper by Bertram [*4*]. Kister [*5*] presented a set of guidelines formulated from Bertram's discussion, and a few additional guidelines were published by Sloley [*6*] in 2009. Despite the available guidelines, Sloley's paper states "Steam condensate pots continue to attract attention because they have so many problems". Ironically, the issue described here, the entry point of the condensate line, was dismissed by Sloley's paper as an "unimportant issue for most installations, put it [the entry point] where you want." This shows that there is much that needs to be understood to solve today's condensate pot problems and to avoid tomorrow's.

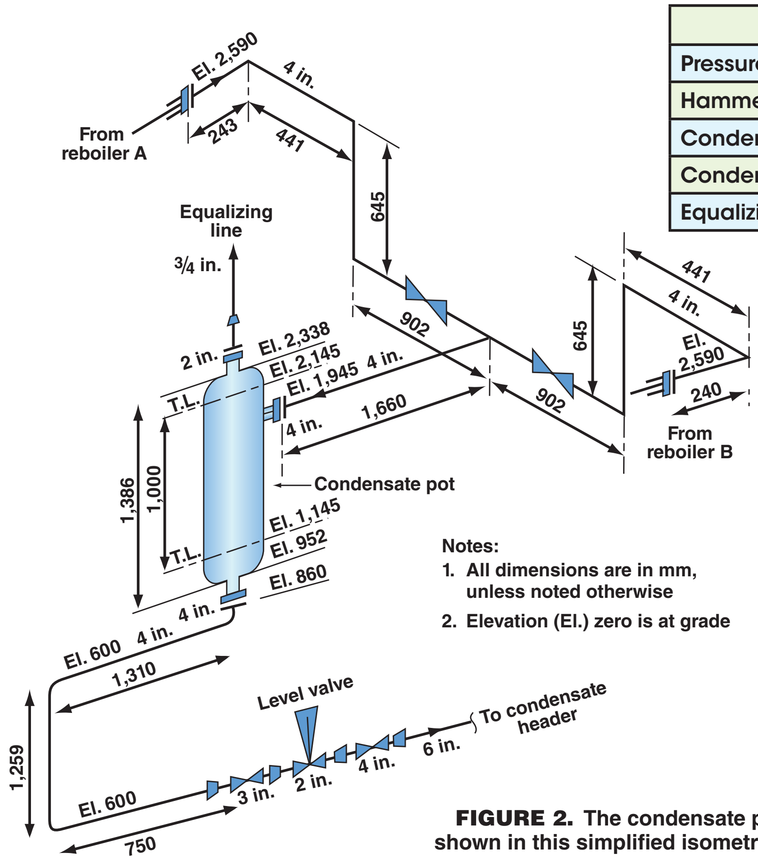

FIGURE 2. The condensate pot system, shown in this simplified isometric drawing, experienced hydraulic hammering

TABLE 1. TEMPERATURE SURVEY		
Pressure, kg/cm^2 gage	4.0	3.2
Hammering?	No	Yes
Condensate drum inlet temperature, °C	72	72
Condensate drum outlet temperature, °C	78	79
Equalizing line near drum, °C	109	120

Process description

Figure 1 shows the deethanizer reboiler system in Braskem's Ethylene Plant 1 in Triunfo, RS, Brazil. The tower is equipped with two vertical thermosiphon reboilers in parallel, one on-line, and the other a spare. The heating medium on the shell side of the reboilers is saturated steam at 154°C (a condensation pressure of 4.4 kg/cm^2 gage). The steam flows via a flowmeter and a flow control valve to the reboilers. A signal from a tray temperature in the stripping section of the deethanizer cascades onto the steam flow controller.

The 4-in. condensate lines leaving each reboiler join into a common 4-in. line that descends before entering the condensate drum, near its top, as shown in Figure 2. Condensate from the drum flows via another 4-in. line, through the drum's level control valve, into the condensate header. There is a ¾-in. pressure equalizing line from upstream of the reboiler-inlet control valve to the top of the condensate drum.

The condensate drum's lower level transmitter tap is located 150 mm above the bottom tangent line of the drum. The upper level transmitter tap is located at the reboiler shell, close to and at the same elevation as the steam inlet. The condensate-drum pressure transmitter is also mounted on the lower level tap, so it measures condensate drum pressure.

Operating experience

The reboiler system experienced the following problems:

Hammering. Whenever the condensate drum pressure dropped below 3.5 kg/cm^2 gage (g), hammering was experienced. Hammering had never occurred when drum pressure exceeded 3.8 kg/cm^2 g.

The lower pressures coincided to lower steam flowrates. The normal steam flowrate to the reboiler was 14.8–15.1 ton/h. At that flowrate, no hammering had occurred. The smallest steam flowrate at which no hammering occurred was 14.5 ton/h. Hammering was experienced at steam flowrates of 14.1–14.5 ton/h. When the hammering occurred, only small fluctuations in steam flowrate to the reboiler were observed, but no major swings were noted. The hammering tended to happen more when the column loads were reduced quickly.

The ¾-in. valve on the equalizing line was normally closed. Whenever the hammering occurred, it continued, whether this valve was open or closed.

Level control. The indication provided by the condensate-drum level indicator appeared unreliable, or at least unsuitable, for control purposes because it was very insensitive to the variations in level-control-valve opening. The only way to maintain stable operation in this system was by operating the condensate-drum level-control valve at constant opening or, in other words, on manual. Operating the system on manual, however, generated a problem of too-slow a condensate removal whenever a large increase in tower feedrate occurred. As a result, when a large feed increase occurred, the reboiler steam-inlet valve tended to open fully.

Temperature survey

To gain insight into the behavior of the system, we conducted temperature surveys under two conditions:

1. When the condensate drum pressure was 4.0 kg/cm^2 g, with no hammering
2. When the condensate drum pressure was 3.2 kg/cm^2 g, and hammering occurred

Surface temperatures were measured using a laser-guided pyrometer, which was calibrated with two measurements of the tower bottom temperatures at two different pressures. The results of the temperature survey are given in Table 1.

The temperature measurements in the equalizing line were made on the condensate drum side of the ¾-in. valve, close to the drum.

Condensate subcooling

At a pressure of 3.0–4.0 kg/cm^2 g, the condensing temperature of steam is 143–151°C. The condensate drum's inlet line should have operated at this temperature, but the temperature survey showed that it operated much colder, at about 72°C. This means that the condensate leaving the reboiler was highly subcooled. In

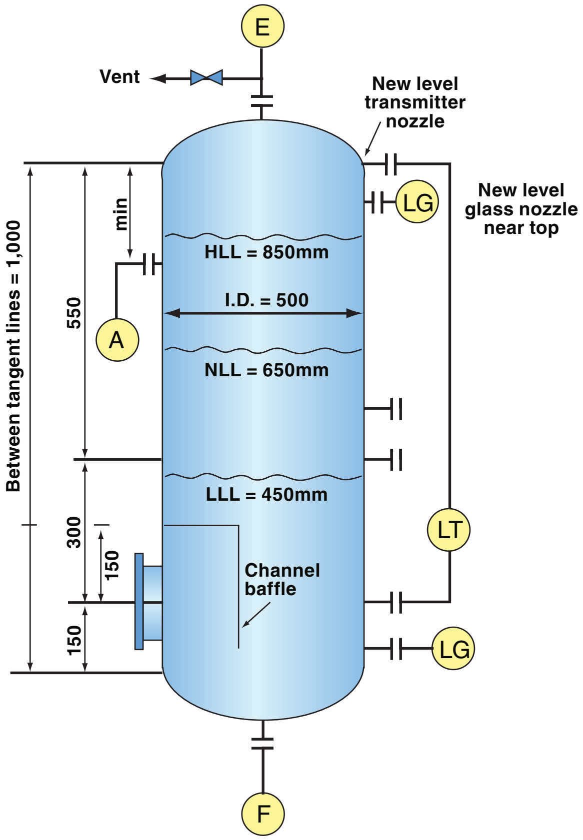

FIGURE 3. These drum modifications eliminated the hammer

fact, it was so highly subcooled that it practically reached the deethanizer bottom (boiling side) temperature of 72°C. Such a high amount of subcooling could occur only if a significant fraction of the reboiler surface area was flooded with condensate.

Subcooling: first mechanism. The prime mechanism that generated the subcooling is as follows: Our heat transfer calculations showed that for non-fouled conditions, the reboiler was generously sized. At a steam flowrate of 15 ton/h (non-hammering condition), with a typical heat-transfer coefficient of 550 kcal/(h m^2·°C), and based on the full actual reboiler area of 355 m^2 (no liquid level in the reboiler), a heat transfer calculation gives a steam condensing temperature of 118°C. At this condensing temperature, the condensing pressure would be 0.9 kg/cm^2 g, which is below the condensate header pressure (1.5 kg/cm^2 g). Condensate would therefore back-flow and flood some of the reboiler area. Condensate in the flooded zone was subcooled by the process liquid.

The steam in the reboiler condensed at a pressure equal to the pressure measured at the condensate drum (4.0 kg/cm^2 g for non-hammering conditions) less the liquid head (about 0.3 kg/cm^2). At 3.7 kg/cm^2 g, the condensing temperature was about 149°C, which gives a reboiler temperature difference (ΔT) of 78°C. With this high ΔT, only 50% of the tube length is needed to satisfy the heat transfer equation. The rest of the tube length would be flooded with condensate and act as a condensate subcooler. Our calculations showed that the tube length performing condensation under hammering conditions was much the same as under non-hammering conditions — about half the tube length.

Subcooling: second mechanism. There was a second mechanism that generated subcooling. Condensate forming in the shell side of the reboiler contains gas bubbles. To gravity-drain this aerated condensate, the condensate drain line needs to be sized for self-venting flow. A correlation by Simpson [*7*] and Sewell [*8*], described on p. 94 of the book Distillation Operation [*5*] shows that the 4-in. reboiler-condensate drain line can only gravity-drain 9 ton/h of aerated condensate flow, which is quite short of the 14–15 ton/h of condensate produced in the reboiler shell. The rest of the condensate accumulated in the reboiler shell, flooding a significant fraction of the reboiler surface area, and promoting the subcooling observed.

Vapor pressure

When a pure liquid is placed in a drum and no other components are present, the drum's pressure equals the vapor pressure of the pure liquid. For water at 72°C the vapor pressure is 0.34 kg/cm^2 absolute, which is a vacuum. So on this basis the condensate drum should have operated under vacuum. The pressure measured in the condensate drum, however, was 3–4 kg/cm^2 g, which could only have happened under one of two conditions: other components were present, or the drum had no vapor space.

There were no apparent sources for other components to enter the condensate drum. The only line that entered the drum was the ¾-in. pressure equalizing line (same component), and its valve was normally closed. There could have been some non-condensables, such as air or carbon dioxide, that either persisted since startup or accumulated during operation. There were no means of purging these from the condensate drum. It is important to note, however, that due to the very low vapor pressure of water at 72°C, as much as about 90% of the vapor space would need to be made up of non-condensables for this explanation to be valid. While plausible, it was highly unlikely. If this explanation was correct, the level in the drum would have been highly sensitive to non-condensable volume and to opening the ¾-in. valve, and this was not observed.

A far more likely explanation is that the drum contained little or no vapor space. In this case, it did not have a real liquid level. With the upper level tap located near the top of the reboiler, the level transmitter measured the liquid level in the reboiler shell, not in the condensate drum. This explanation does not rule out the presence of pockets of non-condensables near the top of the drum, but assigns the high, measured pressure value to the drum behaving like a pipe (or "flooded drum") rather than like a bonafide flash drum.

Opening the level valve lowered the liquid level in the reboiler. This increased the unflooded tube area in the reboiler, and therefore, also increased the reboiler heat transfer. This increase in heat transfer was countered by automatic closure of the flow valve either by the flow controller or by the tray temperature, or both. The condensing pressure in the reboiler dropped, reducing the pressure difference between the reboiler and the condensate header (the condensate pressure downstream of the control valve was about 1.5 kg/cm^2 g). This would lower the condensate flow and raise the level again. There was considerable interaction between the level control and steam flowrate control. Because of the interaction, the drum level indication was insensitive to the level valve opening.

In summary, due to the subcooled liquid, the condensate drum did not operate like a normal flash drum with a normal vapor space. It operated as a flooded vessel. Also, the level transmitter measured the liquid level in the reboiler, not in the condensate drum. This explains why the liquid level was very insensitive to the level valve opening.

Vapor equalizing line

The function of the vapor equalizing line is to help the condensate drum to maintain a vapor space and to compensate for a small degree of heat loss due to subcooling.

The vapor equalizing line was operated with the valve shut. Nevertheless, some steam leaked through the valve into the condensate drum. This can be inferred from the 7°C rise in condensate temperature in the drum and from the high temperatures measured in the line. A heat balance shows that the 7°C rise in condensate temperature coincided with 0.16 ton/h of steam passing via the ¾-in. equalizing line. This steam rate may appear small until one appreciates that it was passing through a ¾-in. line with a shut globe valve. When 0.16 ton/h of 4.4-kg/cm^2 g steam passes through a ¾-in. line, the steam velocity is a very high 70 m/s. Our calculations show that the measured pressure drop would coincide with that through the ¾-in. line with a half-open globe valve (the opening probably due to erosion or corrosion, as the valve was operated shut), so the maximum steam velocity would have been even higher than 70 m/s. Even with the line fully open, the line would have operated near its upper limit. Despite this, the steam flow did very little to help the vapor pressure problem outlined above. The valve was operated shut to minimize hammering. When it was opened wider, the hammering intensified.

Origin of hammering

The only conceivable cause that we could see for the hammering is the collapse of the steam leaking via the ¾-in. equalizing line onto the subcooled condensate. Our theory is as follows:

Based on the heat balance, the steam leakage rate was much the same — about 0.15–0.16 ton/h — for our two temperature surveys (under hammering and non-hammering conditions). The main difference was that under hammering conditions, the pressure drop across the ¾-in. equalizing line was higher as was the temperature near the drum.

Under no-hammering conditions, the condensate drum pressure (3.8–4.0 kg/cm^2 g) was only slightly lower than the steam header pressure (4.4 kg/cm^2 g). It is possible that some condensate ascended from the condensate drum into the vapor equalizing line. The steam condensed on the colder condensate. The steam condensation occurred right at the entrance of the ¾-in. line into the drum. This explains the lower temperature (109°C) measured at the end of the equalizing line.

Under hammering conditions, the higher pressure drop pushed the condensate from the equalizing line into the drum. The hot steam therefore came into contact with a much larger surface of subcooled liquid. Also, the higher pressure drop reduced desuperheating in the equalizing line. This led to the higher temperature of 120°C measured in the equalizing line.

Eliminate subcooling?

Since the root cause of the problem was the intense condensate subcooling, it therefore made sense to solve the problem by eliminating the subcooling.

The prime cause of the subcooling was the excessive reboiler surface area, causing the pressure on the condensing side of the reboiler to fall below the condensate header pressure. This backed liquid up the reboiler, and this liquid was subcooled by the tower bottoms. This subcooling could have been eliminated by allowing condensation of steam at a lower pressure and using a pump or a pumping trap to transfer the condensate to the condensate header.

The second cause of subcooling was the lack of self-venting flow in the reboiler-condensate outlet pipe. This source of subcooling could be eliminated by ensuring a self-venting flow all the way from the reboiler-condensate outlet nozzle to the condensate inlet nozzle on the condensate drum. Based on the Simpson-Sewell method [*5, 7, 8*] discussed earlier, replacing the existing 4-in. line and nozzles with a 6-in. line and nozzles would assure self-venting flow and eliminate the subcooling.

Drawbacks. Eliminating the subcooling was also expected to increase reboiler run length. If the reboiler run length was an issue, this solution would have been attractive. Eliminating the subcooling, however, had two major drawbacks. One, it required installing a new pump or pumping trap and 6-in. nozzles on the reboilers, which was expensive. Second, the hot condensate would flash as it was let down into the condensate system. Since the plant condensate header contained subcooled condensate, the flash steam may have collapsed onto it, resulting in renewed hammering.

Based on these considerations, and since the reboiler was not near its capacity limit and the run length was not an issue, we decided against eliminating the subcooling.

Restoring the drum vapor space

As discussed above, the ¾-in. equalizing line can only supply a limited amount of steam, which is far too small to significantly increase the vapor pressure of the bulk condensate to the point of generating a vapor space in the drum.

The drum vapor space does not need to contact the bulk condensate. If the condensate enters near the bottom of the drum, it passes through the drum and exits out of the bottom without reaching the liquid surface. The drum vapor space is in contact only with the liquid surface in the drum, but not with the subcooled condensate. The pressure in the drum is determined by the vapor pressure at the liquid surface, not by the vapor pressure of the bulk condensate. As long as the liquid surface is kept hot, the drum pressure will be the vapor pressure of the hot liquid, and will be high. As long as the liquid in the upper part of the drum and at the drum surface is not agitated, the only heat loss from the surface to the bulk condensate liquid is due to conduction and a limited amount of bulk movement. This heat transfer rate is

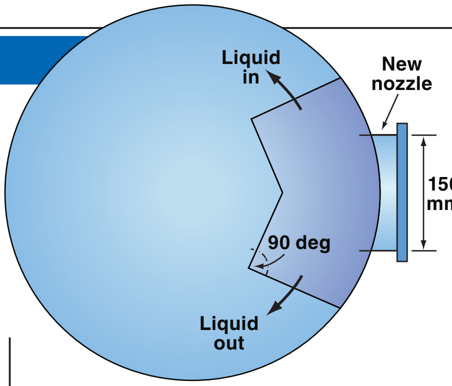

FIGURE 4. Plan view of the channel baffle is shown here

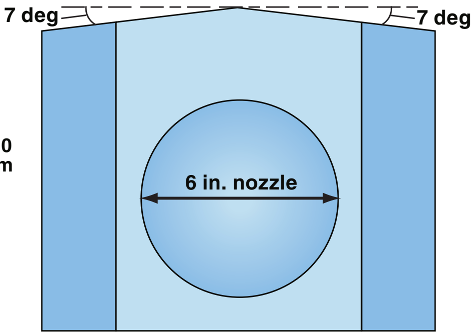

FIGURE 5. This shows the side view of the channel baffle

very low and can easily be matched by the steam from the equalizing line. The liquid layer between the condensate entrance and the liquid surface is a good thermal insulator that shields the surface from the subcooled bulk condensate. As long as the liquid surface in the drum does not contact fresh subcooled condensate, and is not agitated, it is easy to keep hot by the equalizing line.

Theoretically, the heat required to keep the liquid surface hot (and which is supplied by the steam in the equalizing line) equals the heat conduction losses between the hot liquid surface and the subcooled bulk liquid. Practically, some surface agitation and bulk movement of liquid occur in the drum, and these increase the steam demand. A ¾-in. line may still fall short of supplying the required amount, but the experience with 1-in. lines for condensate drum equalizing has had a successful track record.

We therefore decided to solve the problem by restoring the drum vapor space as described above.

Level control

The lower tap of the level transmitter was near the bottom of the condensate drum, and the upper tap was near the top of the reboiler. If there was no condensate accumulation in the reboiler, having the upper tap of the level transmitter in the reboiler would still not have been a good practice, but would have given at least a reasonable measurement. Here, however, the liquid accumulation in the reboiler made it impossible to measure the drum level with the upper tap in the reboiler. The condensate level that needs to be controlled is that in the drum, not in the reboiler. Therefore, the upper tap of the level transmitter needs to be near the top of the condensate drum, not on the reboiler.

It is important to keep the level of liquid in the drum high. If the liquid level falls below the top of the condensate inlet nozzle, the drum vapor space will come into contact with some of the subcooled liquid. The small amount of vapor will collapse onto the subcooled liquid, leading to hammering. For this reason, the top of the inlet nozzle must be liquid-covered at all times. To achieve this, the new condensate inlet nozzle needs to be placed as far down as practicable, while the liquid levels need to be set as high as possible. Figure 3 has some typical numbers. For the same reason, the upper tap of the level transmitter needs to be located as close to the top of the drum as possible. There is also a need of a level glass tap near the top of the drum.

Sloley's recent paper [*6*] dismissed the entry point of the condensate line into the drum as an "unimportant issue for most installations, put it [the entry point] where you want". In our reboiler condensate drum, the converse was experienced: the entry point of the condensate line was crucial, and needed to be as far down as practicable.

Modifications

In order to restore the drum vapor space, we made the following modifications to the system:

1. Relocated the condensate inlet to the condensate drum so that it enters near the bottom of the drum. The centerline of the condensate inlet nozzle is about 150 mm above the bottom tangent line (Figure 3).
2. Resized the condensate line, from the point where the two individual reboiler-condensate outlet lines merge into one, to the new point of entry into the condensate drum, including the new nozzle mentioned in Item 1 above, from 4 to 6 in. This reduces inlet velocity and liquid agitation in the drum entrance.
3. Installed a channel baffle (Figures 4 and 5) — which is covered on top while open on the bottom and sides — inside the condensate drum, in front of the new condensate inlet nozzle. The purpose of this baffle is to minimize bulk movement toward the liquid surface.
4. Installed a new upper level tap as close to the top of the condensate drum as possible (Figure 3), and used this for the level transmitter. Set LLL (low liquid level), NLL (normal liquid level) and HLL (high liquid level) points at 450 mm, 650 mm, and 850 mm, respectively.
5. Installed a new level glass tap near the top of the drum (Figure 3).
6. Replaced the ¾-in. pressure equalizing line by a 1-in. line, including the tie-in to the steam header. The 1-in. valve on this line is a manual throttling globe valve, not a gate valve. The pressure equalizing line is a straight drop, no high or low points.
7. Installed a 1-in. atmospheric vent valve on the condensate drum.
8. Added a vortex breaker to the bottom of the condensate drum.

Recap and results

The findings. A surface temperature survey showed that the reboiler condensate was highly subcooled. The subcooling is attributed primarily to generous sizing of the reboiler

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and also to an undersized condensate drain line. Analysis in terms of vapor pressure led to the conclusion that due to the subcooled liquid, the condensate drum did not operate like a normal drum with a normal vapor space. This explained why the liquid level was insensitive to the level valve opening. The hammering was due to the collapse of steam onto the subcooled condensate.

The solution. The problem was solved by keeping the subcooled condensate away from the drum liquid surface, thereby restoring vapor space to the drum. This was achieved by relocating the condensate entry below the liquid level and adding a channel baffle to keep the subcooled condensate down in the drum. The level measurement was modified to measure the level across the drum only, as opposed to both the drum and reboiler.

The results. Following the modifications, the hammering was entirely eliminated, and good, automatic level control was established. The system has operated for the last nine years at good and stable conditions without any recurrence of the hydraulic hammering, even when operating at low column feedrates (less than 50% of normal feed). Pressures as low as 1.5 kg/cm^2 g were measured in the drum with no hammering (which previously occurred just below 3.5 kg/cm^2 g). The drum level control has been excellent and stable (previously the level control was unreliable and could not be operated in automatic mode). The level transmitter has reliably indicated the drum level. The hammering and instability have become a fading memory. ■

Edited by Dorothy Lozowski

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Note

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Reduce Costs with ‘Step-down’ Filtration

Filtration using ‘step-down’ particle retention can help reduce operating costs and achieve cleaner solutions

Jack H. Berg
Service Filtration Corp.

Huw Williams
Serfilco International Ltd.

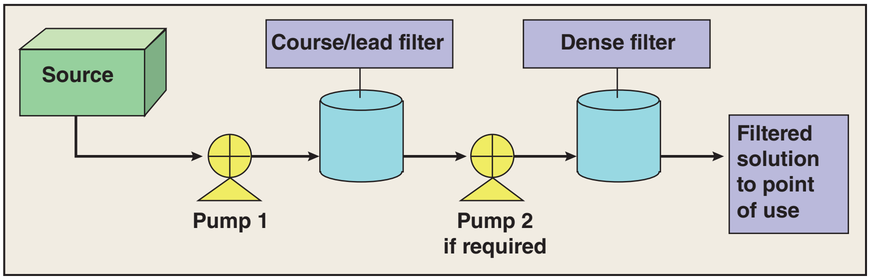

FIGURE 1. A primary filter removes larger-sized particles, allowing the denser media to last longer

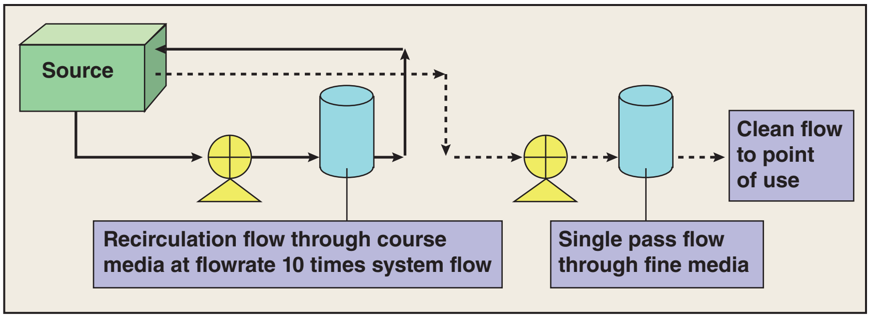

FIGURE 2. In a recirculatory filtration system, the reduction of filter media depends on the type of solids to be retained, as well as their size

Among the challenges of effective solid-liquid filtration is the accumulation of solids on the filter surface, which creates an increasingly dense mass that process fluid must push through. In many applications in the chemical process industries (CPI), a step-down filtration approach has the potential to avoid this difficulty, and at the same time, to cut operating costs and improve solution clarity. Even a 50-µm filter cartridge ahead of a 5- or 10-µm filter could reduce the overall amount of filter media employed by as much as 50%.

Step-down filtration involves a primary (or lead) filter that handles a large quantity of particulate matter or solids before they are allowed to reach a second downstream filter chamber, which is equipped with denser media to capture finer particles. Figure 1 shows the typical piping that would be required. Step-down particle removal works best when a mixture of solid particle sizes exists. The coarser media picks up a large portion of the solids, which allows the denser, and more costly, filter media to last longer. Whether or not an additional booster pump might be required by the first and second stages will depend upon the loss of pressure across the media and the need to meet a required rate of throughput of the filtered solution.

Generally, applications where the step-down filtration process could be employed are those that require retention of extremely fine particles, such as what is now being provided by 1- to 10-µm filter cartridges, surface-type media (pleated or disc or bags), or precoat filters using diatomaceous earth. In the latter case, the frequency of servicing, whether by backwashing or changing of the media itself, would be prohibitive because of the low solids-holding capacity of the media.

Recirculatory filtration

While Figure 1 depicts an inline system, where a solution containing solids would pass once through the process, a step-down filtration approach can also be effective in cases where solution from a reservoir is recirculated through the filter apparatus. Recirculatory systems can be applied to engine lubrication oil or fluids used for hydraulics. Such filter systems are also used to recirculate water for swimming pools. Applications that could benefit from recirculatory filtration are also in food processing (such as syrups, oils, detergents, brine and beer).

Recirculation can be beneficial in cases where a given filter media stops most, but not all, of the solids that must be retained. Allowing a second, third or fourth pass through the filter may produce the desired result. To illustrate, consider a filter medium with a retention efficiency of 90% of 5-µm particles. This medium will also remove a lower percentage of smaller particles (for example, 50% of 3-µm particles). If the porosity of the media remains unchanged, the filter could be expected to pick up 50% of the remaining 3-µm particles per pass (first pass removes 50% of 100; second pass removes 50% of 50; third 50% of 25; and so on). In

this way, a recirculatory system offers the greatest potential of reducing the amount of filter media consumption.

Combining recirculation with the step-down filtration approach yields a situation in which a solution would pass through a primary filter several times before being allowed to enter the filter with denser media. For instance, in an application where water comes from an outside source before passing through a filter (such as reverse osmosis, carbon or water softening) an additional tank would be required, along with a pump and an auxiliary filter. The filter would be designed to operate at a flowrate exceeding that the of the required flow to the system (Figure 2). Thus, a system requiring 10 gal/min could be recirculated at 10 times the system's required flow so that at 100 gal/min, the liquid would pass through the filter at least 10 times before being allowed to pass on to the denser filter media required for the process.

Quantifying the reduction in filter media in such a system would depend upon the type and size of solids to be retained, as well as the velocity across the auxiliary media, so as to retain as high a percentage as possible. As the size of the reservoir or the recirculation rate is modified, the amount of denser media required will be reduced, saving considerable money. The savings would be due to lower labor costs for servicing, lower disposal costs and a reduction in the volume of waste being landfilled.

Filter types

The type of filter, along with its media, will further complement the success of this modification of your process. Several types are available. One "multimedia" type system applies a backwash to clean the media and isolate the dirt that has been trapped either for further treatment or safe disposal. Gravity-type systems employ roll media, which is disposable. Both types are generally used for recirculation but can also be used as final trap filters. Manual-type filters that require cleaning or replacement in servicing, would generally be employed where flowrates, solids and the type of fluid to be clarified are under consideration. On the other hand, continuous process lines where hazardous waste is picked up by the media, such as in a nuclear plant, would lend itself to an automatic type of filter, which could employ sand or straining where the interruption caused by the backwashing cycle of a sand filter would have to be minimized, and the liquid when backwashed might have to be retained in storage for further clarification. ■

Edited by Scott Jenkins

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Tank Vapors: Optimize Ejector Sizing for Better Control

Properly sized ejector stations can save capital costs and reduce downtime

Graeme H. Bryden
Vista-IMV Joint Venture Corp.

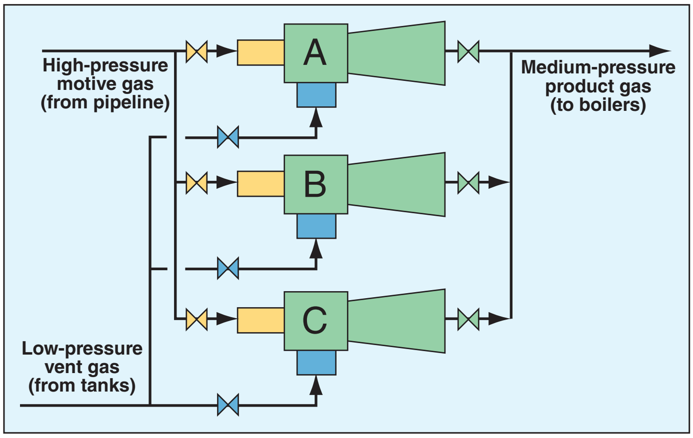

FIGURE 1. Shown here is a schematic for an ejector station with three ejectors that are installed in parallel

Steam-assisted, gravity-drainage (SAGD) operations employ large tanks that vent flammable and sometimes toxic gases. Safety and environmental concerns often require engineers to design vapor-recovery units (VRUs) to collect these gases and redirect them to a useful location — frequently for use as a fuel gas in a steam-generation system.

When choosing a VRU setup for an SAGD facility, the two most common options are compressor-based and ejector-based designs. Compressor control and recycle schemes enable greater operating turndown, allowing the compressor to operate over a range of flows and providing better control. Similarly, compressors can accept small upsets with little or no action required by the staff. By contrast, each single ejector is either on or off.

Compressors frequently run on electricity or burn fossil fuels in an engine. Ejectors, on the other hand, require a motive gas from a high- or medium-pressure pipeline. The energy comes from the pressure of the stream, and none of the fluids are consumed inside the ejectors. One potential drawback, however, is that single ejectors have effectively no turndown capabilities. Thus, they lack the operating flexibility of compressor-based VRUs.

The use of an ejector station — which involves a group of ejectors operating in parallel — can overcome the flexibility constraints of a single ejector. Figure 1 shows how a three-ejector station is set up. Operators activate individual ejector units according to tank-venting rates. As the tank pressure increases, additional ejectors are activated to relieve the increased vapor flow. When tank pressures decrease, operators deactivate individual ejectors until the tank pressure has stabilized to a desired setpoint.

The ability to maintain fine control using a multi-ejector-based VRU can help avoid unwanted scenarios. For instance, operating ejectors below the required flowrate can result in tanks venting their vapor contents to the atmosphere. Similarly, operating ejectors at flows higher than necessary may require flaring if the downstream steam generators cannot accept the increased gas flow. The need for flaring is not only expensive, but it increases carbon emissions, and prolonged flaring may require a plant shutdown for regulatory compliance. Facilities are most likely to flare when steam generators become deactivated but production at the facility — and therefore tank venting — continues. An engineer can reduce the likelihood of flaring by efficiently sizing ejectors and turning off any ejectors that are not required to relieve pressure from tanks. The method of staggering ejector sizes in parallel service (discussed below) gives operators maximum control and can help reduce flaring.

TABLE 1. TWO-EJECTOR STATION

Name	Sizing formula	Sizing result	
Ejector B	X	66.7%	
Ejector A	$X/2$	33.3%	<– Maximum error
Total	$X+X/2=$	100.0%	

The primary considerations before determining the VRU arrangement are the desired VRU maximum capacity (referred to here as 100%), and how stable the flowrates are. If an ejector station is chosen instead of a compressor, designers must also decide how finely to control the system.

Increasing the ejector count inside a station increases the number of control points (or steps) for the system, leading to finer control. During normal operation, the vented flowrate may be 45% of the maximum required capacity of vented gas. For example, if a tank system vents 600 kg/h of gas as a maximum case scenario, and the ejec-

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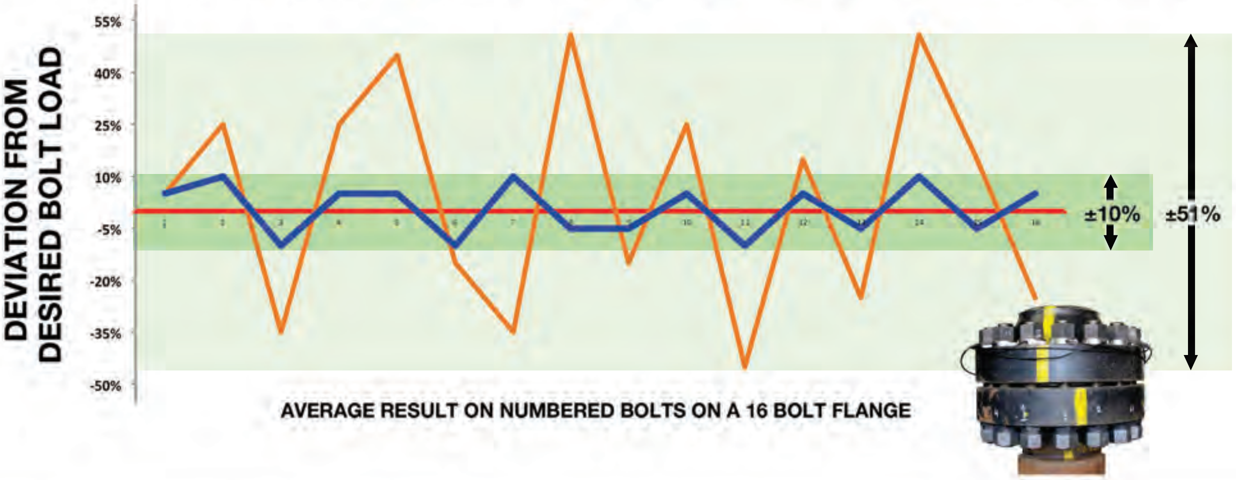

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tor station runs at 45% capacity, then the vent gas is moving through at 270 kg/h. To handle 45% of the maximum vented flowrate, the operator activates ejectors until the vented flow requirements have been satisfied.

For this case, if we have four ejectors, each able to handle 25% of the maximum flow to the ejector station, we will need to activate two of the four ejectors. If, however, the design uses three ejectors, each capable of handling 33% of the max flow to the ejector station, we would need to activate two of the three ejectors, and our control wouldn't be as fine. The use of more ejectors allows a larger number of steps between 0 and 100% to be activated, providing more control points and finer operating control.

Table 1 shows the most efficient way to stagger the sizes for a two-ejector VRU station. The *X* term in Tables 1, 2 and 3 refers to the size of the largest ejector in that station. For instance, for the two-ejector station in Table 1, *X* refers to 66.7% of the maximum vent rate. For the three-ejector station in Table 2, *X* refers to 57.1% of the maximum vent rate. For the four-ejector station in Table 3, *X* refers to 53.3% of the maximum vent rate.

The maximum error notes the largest difference the setup can have between the vent gas flow and the flow of vent gas through the ejectors. Every unit of vent gas requires about five units of motive gas for the ejector to operate properly. So if vent flows become large, the motive gas flows become much larger, and could overwhelm the boilers, requiring excess product gas to be burned in a flare system.

In general, a two-ejector system is preferred when the maximum vent-gas flow to an ejector station is relatively small. For such small vent rates, fine control is not usually required as the boilers can accept the relatively small amount of added gas.

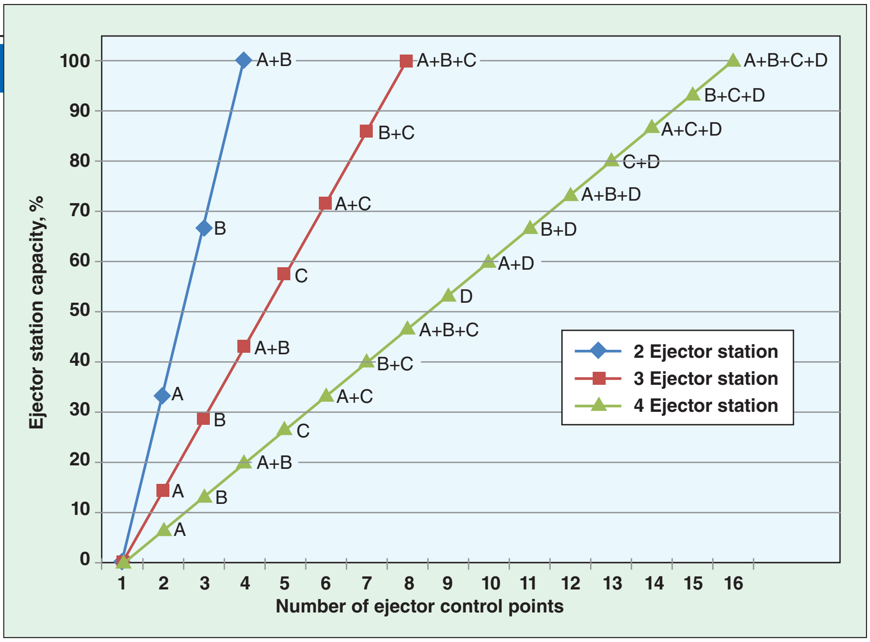

FIGURE 2. As this visual display of staggered ejector control points shows, the number of control options increases as the number of ejectors increases. The letters refer to different ejectors in the array

TABLE 2. THREE-EJECTOR STATION

Name	Sizing formula	Sizing result	
Ejector C	*X*	57.1%	
Ejector B	*X*/2	28.6%	
Ejector A	*X*/4	14.3%	<– Maximum error
Total	*X*+*X*/2+*X*/4=	100.0%	

TABLE 3. FOUR-EJECTOR STATION

Name	Sizing formula	Sizing result	
Ejector D	*X*	53.3%	
Ejector C	*X*/2	26.7%	
Ejector B	*X*/4	13.3%	
Ejector A	*X*/8	6.7%	<– Maximum error
Total	*X*+*X*/2+*X*/4+*X*/8=	100.0%	

Table 2 shows the most efficient way to stagger the sizes for a three-ejector VRU station. Such a design is useful when the total flow from several ejector stations could send more fuel to the downstream steam generators than they can accommodate. This setup can also handle sizable fluctuations without the need to activate or deactivate ejectors in the station.

Table 3 shows the most efficient way to stagger the ejector sizes in a four-ejector VRU station. This arrangement allows for tight flow control, so it is suitable for ejector stations with large flows. But, it requires careful monitoring to ensure that fluctuations do not create system problems.

Increasing the ejector count at a station with more than four ejectors provides even finer control. However, optimizing ejector control using five or more ejectors in a station (maximum error = 3.2%) does not allow much room for fluctuations in the process, and requires close monitoring.

Based on the ejector sizes provided in Tables 1, 2 and 3, Figure 2 provides a visual representation of how finely operators can control ejector stations. Each point on the graph indicates a setpoint to which the ejector station can be controlled. ■

Edited by Suzanne Shelley

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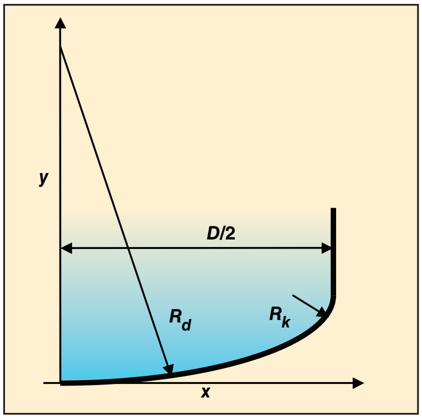

FIGURE 1. This figure shows the relevant radii of curvature and the coordinate system used for a vertical tank

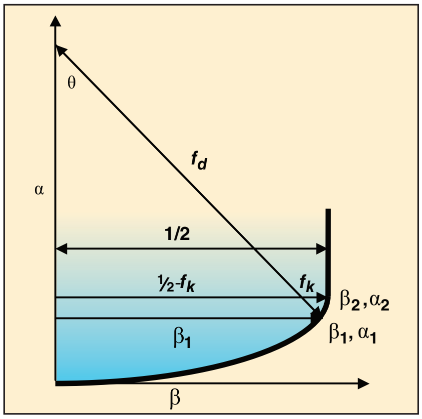

FIGURE 2. This two-dimensional view of the tank head is shown using dimensionless parameters

This article presents equations that allow the user to calculate liquid volume as a function of liquid depth, in both vertically and horizontally oriented tanks with dished heads. The equations accommodate all tank heads that can be described by two radii of curvature (torispherical heads). Examples include: ASME flanged & dished (F&D) heads, ASME 80/10 F&D heads, ASME 80/6 F&D heads, standard F&D heads, shallow F&D heads, 2:1 elliptical heads and spherical heads. Horizontal tanks with true elliptical heads of any aspect ratio can also be accommodated using this methodology.

This approach can be used to prepare a lookup table for a specific tank, which yields liquid volumes (and weights) for a range of liquid depths. The equations can also be applied directly to calculate the liquid volume for a measured liquid depth in a specific tank. Such calculations can be executed using a spreadsheet program, a programmable calculator or a computer program. Spreadsheets that perform these calculations are available from this magazine (search for this article online at www.che.com, and see the Web Extras tab).

Problem background

Tanks with dished heads are found throughout the chemical process industries (CPI), in both storage and reactor applications. In some cases, liquid volume calibrations of these vessels exist, but for many, the liquid volumes must be calculated. Traditional methods of calculation can be cumbersome, and some lack precision or offer little or no equation derivation.

The equations presented below are mathematically precise and have a detailed derivation. The spreadsheets that are offered to perform the calculations produce a table of liquid volumes for a range of liquid depths that are suitable for plant use. This table is generated by entering four parameters that define key tank dimensions. An operator could use such a spreadsheet table in lookup mode, using interpolation if necessary. One could also turn the tabular values into a plot.

Each spreadsheet also has a calculator function, which requires the user to enter only the tank geometry parameters and liquid depth and the spreadsheet quickly returns the liquid volume. The spreadsheets can be used with handheld devices (such as a Blackberry or iPhone) that can run an Excel spreadsheet. For certain applications, one may want to show only the calculator function for a given vessel, so that an operator would only need to enter a liquid level to quickly calculate the corresponding liquid volume.

A number of tank heads have a dished shape, and the equation development discussed below handles all of those where the heads can be described by two radii of curvature.

Doolittle [*1*] presents a graphical representation of liquid volumes in both horizontal and vertical tanks with spherical heads. The calculation of the liquid in the heads is approximate. The graph shows lines for tank diameters from 4 to 10 ft, and tank lengths from 1 to 50 ft. The accuracy of the liquid volume depends on certain approximations and the precision of interpolations that may be required.

Perry [*2*] states that the calculation of volume of a partially filled tank "may be complicated." Tables are given for horizontal tanks based on the approximate formulas developed by Doolittle.

Jones [*3*] presents equations to calculate fluid volumes in vertical and horizontal tanks for a variety of head styles. Unfortunately, no derivation of those equations is offered. As of the time of this writing, there were no Internet advertisements offering spreadsheets to solve the equations. Meanwhile, without adequate equation derivations, one would be unsure what one is solving, and thus, the results would be suspect.

By contrast, this article provides

TABLE 1. STANDARD DISHED TANK-HEAD TYPES

Tank head style	Dish radius factor, f_d	Knuckle radius factor, f_k
ASME flanged & dished (F&D)	1.000	0.060
ASME 80/10 F&D	0.800	0.100
ASME 80/6 F&D	0.800	0.060
2:1 Elliptical	0.875	0.170
Spherical	0.500	0.500
Standard F&D	1.000	2 in./D
Shallow F&D	1.500	2 in./D

exact equations for the total volume of the heads and exact equations for liquid volumes, for any liquid depth for any vertical or horizontal tank with dished heads. The popular 2:1 elliptical heads are actually fabricated as approximate shapes by using variations of the two-radii designs.

In addition, this article also presents the exact equations for true elliptical heads of any ratio (not limited to 2:1). Provided below are descriptions of the equation development, guidance on how to use the spreadsheets, and a discussion of a sample application for both a vertical and a horizontal tank.

Types of dished tank heads

Figure 1 shows the relevant radii of curvature and the coordinate system used. All symbols are defined in the Nomenclature Section on p. 59. It is convenient to present the equation development in terms of dimensionless variables. By normalizing all lengths by the tank diameter, the diameter is absent from all equations expressed in the dimensionless coordinates. The two radii (dish radius and knuckle radius) that describe the dished heads can be expressed as follows:

$$R_d = f_d D \qquad (1)$$

$$R_k = f_k D \qquad (2)$$

Table 1 presents standard dished tank heads that are described by this work.

Radius as a function of depth

For convenience, the derivation in this section describes a tank with vertical orientation. However, the derivation applies to horizontal tanks as well. The equations are used in the integrations described in the subsequent two sections, which yield the liquid volumes for vertical and horizontal tanks.

For the dished heads considered here, two radii define the shape. The bottom region of the head is spherical and has a radius that is proportional to the diameter of the cylindrical region of the tank (see Equation 1). This is referred to as Region 1.

Above that is Region 2, which is called the knuckle region. Its radius of curvature is shown in Figure 1. It can also be normalized by the tank diameter (see Equation 2).

The last concept needed to define the dish shape is that the curvatures of the two radii are equal at the plane where Regions 1 and 2 join. That will be explained further in the equation development that follows.

The coordinate system for the equations is shown in Figure 1. The origin of the coordinate system is chosen to be at the bottom-most point in the tank. For Region 1, the equation for the tank radius, *x*, in terms of the height, *y*, is as follows:

$$x^2 + \left(f_d D - y\right)^2 = f_d^2 D^2 \qquad (3)$$

This equation can be expressed via the following dimensionless variables:

$$\alpha = y / D \qquad (4)$$

$$\beta = x / D \qquad (5)$$

Substituting Equations 4 and 5 into Equation 3 gives the final dimensionless equation for Region 1, as shown in Equation 6:

$$\beta^2 + \left(f_d - \alpha\right)^2 = f_d^2 \qquad (6)$$

For Region 2, the equation for the tank radius, *x*, in terms of the height, *y*, is:

$$\left(x - x_k\right)^2 + \left(y - y_k\right)^2 = f_k^2 D^2 \qquad (7)$$

Where (x_k, y_k) is the coordinate location of the center of the knuckle radius. By substituting Equations 4 and 5, Equation 7 is made dimensionless, as shown in Equation 8:

$$\left(\beta - \beta_k\right)^2 + \left(\alpha - \alpha_k\right)^2 = f_k^2 \qquad (8)$$

The *x*-coordinate of the knuckle radius, x_k, must be:

$$x_k = \frac{D}{2} - f_k D \qquad (9)$$

Equation 9 can be made dimensionless, as shown in Equation 10:

$$\beta_k = 0.5 - f_k \qquad (10)$$

Making that substitution into Equation 8 gives the final dimensionless equation for Region 2:

$$\left(\beta - 0.5 + f_k\right)^2 + \left(\alpha - \alpha_k\right)^2 = f_k^2 \qquad (11)$$

Region 3 is the cylindrical portion of the tank with a constant diameter, with β equaling 0.5.

Next, one must determine the coordinates of the point where the curves for Regions 1 and 2 come together. Working with the dimensionless variables, β and α, and using the subscript 1 to denote the top of Region 1, we seek to find α_1 (the dimensionless coordinate of the top of Region 1), such that Equations 6 and 11 both give the same value for α_1 (given the same value of β_1), and such that the curvature is continuous at the intersection.

Figure 2 is a two-dimensional view of the tank head using dimensionless parameters. The radius of the spherical region is drawn through the origin of the knuckle radius. The point where that line intersects the head identifies where Regions 1 and 2 join. At that point, the curvatures of the spherical region and the knuckle region are identical. The angle between the radius of that spherical region and the tank center line is denoted as θ. We can write the follow three trigonometric expressions involving that angle:

$$\sin\theta = \frac{1/2 - f_k}{f_d - f_k} \qquad (12)$$

$$\sin\theta = \frac{\beta_1}{f_d} \qquad (13)$$

$$\cos\theta = \frac{f_d - \alpha_1}{f_d} \qquad (14)$$

Recognizing the following trigonometric identity

$$\sin^2\theta + \cos^2\theta = 1 \qquad (15)$$

We substitute Equations 12 and 14 into Equation 15 and solve for α_1:

$$\alpha_1 = f_d\left[1 - \sqrt{1 - \left(\frac{1/2 - f_k}{f_d - f_k}\right)^2}\,\right] \qquad (16)$$

The value of β_1 can be calculated by combining Equations 12 and 13:

TABLE 2. DEFINED AND CALCULATED PARAMETERS FOR DISHED TANK HEADS

Tank head style	f_d	f_k	α_1	β_1	α_2	β_2
ASME F&D	1.000	0.06	0.1163166103	0.4680851064	0.1693376137	0.5
ASME 80/10 F&D	0.800	0.10	0.1434785547	0.4571428571	0.2255437353	0.5
ASME 80/6 F&D	0.800	0.06	0.1567794689	0.4756756757	0.2050210088	0.5
2:1 Elliptical	0.875	0.17	0.1017770340	0.4095744681	0.2520032103	0.5
Spherical	0.500	0.50	0.5000000000	0.5000000000	0.5000000000	0.5

TABLE 3. RATIO OF TOTAL HEAD CAPACITY TO D^3 FOR VARIOUS DISHED HEADS

Tank head style	f_d	f_k	α_1	$\alpha_2 = \alpha_k$	C
ASME F&D	1.000	0.06	0.116317	0.169338	0.0809990
ASME 80/10 F&D	0.800	0.10	0.143479	0.225544	0.1098840
ASME 80/6 F&D	0.800	0.06	0.156779	0.205021	0.0945365
2:1 Elliptical	0.875	0.17	0.101777	0.252003	0.1337164
Spherical	0.500	0.50	0.500000	0.500000	0.2617994

$$\beta_1 = f_d\left(\frac{1/2 - f_k}{f_d - f_k}\right) \qquad (17)$$

To calculate α_2 we apply the Pythagorean Theorem to the right triangle whose hypotenuse is a line between the origin of the spherical radius and the origin of knuckle radius, as shown in Equation 18:

$$\left(1/2 - f_k\right)^2 + \left(f_d - \alpha_2\right)^2 = \left(f_d - f_k\right)^2 \qquad (18)$$

Solving that for α_2 gives:

$$\alpha_2 = f_d - \sqrt{f_d^2 - 2f_d f_k + f_k - 1/4} \qquad (19)$$

α_k is located at the top of Region 2, so

$$\alpha_2 = \alpha_k \qquad (20)$$

At the top of Region 2, the head radius equals the radius of the cylindrical portion, so β_2 equals ½.

For Region 3, the radius is constant and is simply half the tank diameter. So, the expression for the tank radius is shown in Equation 21:

$$\beta = 0.5 \quad \text{for} \quad \alpha_2 \le \alpha \le \alpha_3 \qquad (21)$$

It is not necessary to construct equations for β as a function of α in Regions 4 and 5. For vertical tanks, the volumes for liquid levels in those regions can be calculated from the equations for Region 1 and 2 (presented below). For horizontal tanks, the liquid volume in the right-hand head equals that of the left-hand head for the symmetrical tanks discussed here.

The value for α_1 (top of Region 1) for each head style was determined by solving Equation 16. β_1 is given by Equation 17. α_2 is equivalent to α_k, and its value is given by Equation 19. At the top of the tank, α_5 is the tank height, H, divided by the diameter, or

$$\alpha_5 = H / D \qquad (22)$$

Since the two heads are taken to be the same shape:

$$\alpha_4 = \alpha_5 - \alpha_1 \qquad (23)$$

$$\alpha_3 = \alpha_5 - \alpha_2 \qquad (24)$$

So, the values of α_1 through α_5 are thusly constructed.

Values for α_1, β_1, α_2 and β_2 for the various tank head styles considered here are summarized in Table 2.

One should recognize that the parameters in Table 2 apply to all of the torispherical tank head styles, regardless of the tank diameter. That is one of the benefits of working with the dimensionless parameters.

One use for the α_2 values would be to calculate the distance from the end of a dished head to the plane through the boundary between Regions 2 and 3. So, for example, if one had ASME flanged and dished (F&D) heads of a tank with a 100-in. I.D. for which α_2 equals 0.1693376137, that length would be 0.1693376137 times 100 in., or 16.934 in.

The last two tank head styles listed in Table 1 (standard flanged & dished, and shallow flanged & dished) require a somewhat different treatment, since the radius of curvature for the knuckle region in each case is a fixed 2 in. rather than a fixed fraction of the tank diameter. While all the equations above still apply, one must determine the α and β parameters in Table 2 for each individual tank.

So, for example, if one had standard flanged & dished heads on a 100 in. dia. tank, f_k would be 0.02 and f_d would be 1.0. Those values would be used in Equation 16 to find α_1. One would, in turn, use the appropriate equations to calculate β_1, α_2, and β_2. All the equations in the following sections for the tank volume and liquid volume also apply.

Liquid volume as a function of depth for vertical tanks

Liquid volume in Region 1. The liquid volume, v_i, in any tank region i is simply

$$v_i = \int_{y_{i-1}}^{y} \pi x^2 dy \qquad (25)$$

Replacing x and y by their dimensionless expressions in Equations 4 and 5 gives

$$v_i = \pi D^3 \int_{\alpha_{i-1}}^{\alpha} \beta^2 d\alpha \qquad (26)$$

For Region 1, substituting for β^2 from Equation 6 and integrating gives

$$v_1 = \pi D^3 \left[f_d \alpha^2 - \alpha^3 / 3\right] \quad \text{for} \quad 0 \le \alpha \le \alpha_1 \qquad (27)$$

The total capacity of Region 1, denoted as V_1, can be calculated by putting α_1 and a value for D into Equation 27. This will also be the total tank capacity of Region 5, denoted as V_5.

Liquid volume in Region 2. For Region 2, the liquid volume is calculated using Equation 28:

$$v_2 = \pi D^3 \int_{\alpha_1}^{\alpha} \beta^2 d\alpha \qquad (28)$$

Substituting for β from Equation 11 and integrating gives Equation 29:

Equation 29: (see box on p. 56) (29)

As discussed above, α_k is identical to α_2 (see Equation 20), so that substitution could be made in Equation 29.

The total capacity of Region 2, denoted as V_2, can be calculated by putting α_2 in place of α in Equation 29. This will also be the total tank capacity of Region 4, denoted as V_4.

Liquid volume in Region 3. Carrying out the integration in Equation 26 for Region 3 with the substitution from Equation 21 yields the liquid volume in Region 3, as shown next:

$$v_3 = \frac{\pi D^3}{4}\left[\alpha - \alpha_2\right] \quad \text{for} \quad \alpha_2 \le \alpha \le \alpha_3 \qquad (30)$$

EQUATIONS 29, 31, 36

$$v_2 = \pi D^3 \{ [(0.5 - f_k)^2 + f_k^2] (\alpha - \alpha_1) - \frac{1}{3} [(\alpha - \alpha_k)^3 - (\alpha_1 - \alpha_k)^3] + (0.5 - f_k) [(\alpha - \alpha_k) \sqrt{f_k^2 - (\alpha - \alpha_k)^2} - (\alpha_1 - \alpha_k) \sqrt{f_k^2 - (\alpha_1 - \alpha_k)^2} + f_k^2 \sin^{-1} \frac{(\alpha - \alpha_k)}{f_k} - f_k^2 \sin^{-1} \frac{(\alpha_1 - \alpha_k)}{f_k}] \} \text{ for } \alpha_1 \le \alpha \le \alpha_2 \quad (29)$$

$$v_4 = V_4 - \pi D^3 \{ [(0.5 - f_k)^2 + f_k^2] (\alpha_5 - \alpha - \alpha_1) - \frac{1}{3} [(\alpha_5 - \alpha - \alpha_k)^3 - (\alpha_1 - \alpha_k)^3] + (0.5 - f_k) [(\alpha_5 - \alpha - \alpha_k) \sqrt{f_k^2 - (\alpha_5 - \alpha - \alpha_k)^2} - (\alpha_1 - \alpha_k) \sqrt{f_k^2 - (\alpha_1 - \alpha_k)^2} + f_k^2 \sin^{-1} \frac{(\alpha_5 - \alpha - \alpha_k)}{f_d} - f_k^2 \sin^{-1} \frac{(\alpha_1 - \alpha_k)}{f_d}] \} \text{ for } \alpha_3 \le \alpha \le \alpha_4 \quad (31)$$

$$C = \pi [f_d \alpha_1^2 - \alpha_1^3 / 3] + \pi \{ [(0.5 - f_k)^2 + f_k^2] (\alpha_2 - \alpha_1) + \frac{1}{3} (\alpha_1 - \alpha_k)^3 + (0.5 - f_k) [(\alpha_k - \alpha_1) \sqrt{f_k^2 - (\alpha_1 - \alpha_k)^2} - f_k^2 \sin^{-1} \frac{(\alpha_1 - \alpha_k)}{f_k}] \} \quad (36)$$

The total capacity of Region 3, denoted as V_3, can be calculated by putting α_3 into Equation 30 in place of α.

Liquid volume in Region 4. If the liquid level is in Region 4, the volume can be determined from the volume equation for Region 2, Equation 29. For a liquid level α in Region 4, the height of the tank's vapor space would be $(\alpha_5 - \alpha)$. The volume of the vapor space in Region 4 would be equivalent to the liquid volume in Region 2 if the level were at a depth of $(\alpha_5 - \alpha)$. So, to calculate the liquid volume in Region 4, we take the capacity of Region 4 (equivalent to the capacity of Region 2) and subtract the vapor space in Region 4.

Equation 31: (see box above) **(31)**

Liquid volume in Region 5. In an analogous manner, the liquid volume in Region 5 is:

$$v_5 = V_5 - \pi D^3 \left[f_d (\alpha_5 - \alpha)^2 - (\alpha_5 - \alpha)^3 / 3 \right] \text{ for } \alpha_4 \le \alpha \le \alpha_5 \quad (32)$$

Tank capacity and total liquid volume. The total tank capacity is

$$V_T = 2V_1 + 2V_2 + V_3 \quad (33)$$

The final expression for the liquid volume is shown in Equation 34:

$$v = \sum_{i=1}^{i-1} V_i + v_i \quad (34)$$

Where the v_i and V_i terms are given by Equations 27, 29, 30, 31, and 32 for the five regions.

Capacities of dished heads. The total head volume (capacity) for each dished head considered in this article can be calculated by adding the volumes of Region 1 (Equation 27 with $\alpha = \alpha_1$) and Region 2 (Equation 29 with $\alpha = \alpha_2$). One can see the result will be an equation of this form:

$$V_h = CD^3 \quad (35)$$

Where C is calculated as:

Equation 36: (see box above) **(36)**

Table 3 shows the value of C for each type of head considered here.

Perry [2] gives an approximate value for C for an ASME F&D head as 0.0809, which is quite close to the precise value given in Table 3.

Liquid volume as a function of depth for horizontal tanks

The liquid depth, d, in a horizontal tank is measured in the cylindrical region. Calculation of the liquid volume in the cylindrical region of the tank is straightforward; calculating the liquid volume in the two dished heads is more challenging. First, one needs to recognize that every possible tank cross-section formed by planes perpendicular to the tank's center axis will be a circle. In the dished regions, if there is liquid at any given plane, the area of that liquid A_L will be what is termed a segment of the circular cross-section. One can calculate the liquid volume between any two cross-sectional planes by integrating the following:

$$v_L = \int_{y_a}^{y_b} A_L dy \quad (37)$$

The coordinate system for horizontal tanks is shown in Figure 3. We begin the development of the liquid volume equation by looking at the cylindrical region, and follow that by dealing with the dished regions.

Liquid volume in the cylindrical region. If one envisions a cross-section perpendicular to the tank axis in the cylindrical region of a horizontal tank with a liquid depth d, the area of a segment representing the liquid would have an area of

$$A_{LC} = 2\int_{-R}^{-(R-d)} x dy \quad (38)$$

where the center of the coordinate system is the tank's centerline in a plane perpendicular to that centerline, and R is the tank radius. The equation for the circle formed by the intersection of the tank with that plane is shown in Equation 39:

$$x^2 + y^2 = R^2 \quad (39)$$

Substituting Equation 39 into 38 and integrating gives:

$$A_{LC} = (d - R)\sqrt{2dR - d^2} + R^2 \sin^{-1} \frac{d - R}{R} + \frac{\pi R^2}{2} \quad (40)$$

Defining a dimensionless liquid depth

$$\delta = d / D \quad (41)$$

and substituting Equation 41 into Equation 40, and replacing R with $D/2$ gives

$$A_{LC} = D^2 \left[(\delta - \frac{1}{2})\sqrt{\delta - \delta^2} + \frac{1}{4} \sin^{-1}(2\delta - 1) + \frac{\pi}{8} \right] \quad (42)$$

Given that the length of the cylindrical region is $(\alpha_3 - \alpha_2) D$, the volume of liquid in the cylindrical region is just area times length, or

$$v_{LC} = (\alpha_3 - \alpha_2) D^3 \left[(\delta - \frac{1}{2})\sqrt{\delta - \delta^2} + \frac{1}{4} \sin^{-1}(2\delta - 1) + \frac{\pi}{8} \right] \quad (43)$$

Liquid volume in the tank heads. The liquid volume in the dished regions is arrived at by analogous reasoning to that used for the cylindrical region. Again, planes constructed perpendicular to the tank axis will intersect the dished head giving circular shapes.

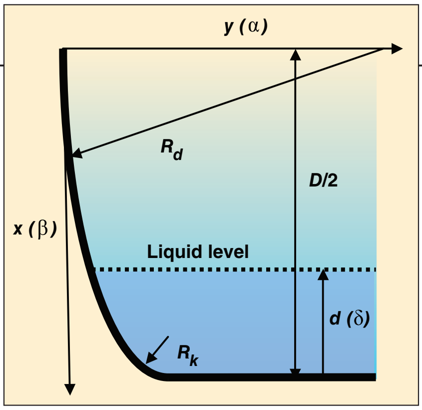

FIGURE 3. The coordinate system for a horizontal tank is shown here

EQUATION 48

$$A_{LD} = D^2 \left[(\delta - \frac{1}{2})\sqrt{-\delta^2 + \delta + \beta^2 - \frac{1}{4}} + \beta^2 \sin^{-1} \frac{\delta - \frac{1}{2}}{\beta} + \frac{\pi\beta^2}{2} \right]$$

$$\text{where } \left(\frac{1}{2} - \beta\right) \le \delta \le \left(\frac{1}{2} + \beta\right) \qquad \textbf{(48)}$$

The radii of those circles will depend on the curvature of the dish and, as such, will vary with α, the dimensionless distance from the left-hand end of the tank. Also, for a given liquid depth in the cylindrical region, the liquid depth at a cross-section in the dished head will be less than in the cylindrical region because of the dish curvatures.

Referring to Figure 4, a schematic view looking toward the left-hand tank dished head, the outer circle represents the cylindrical diameter and the inner circle represents a cross-section in the dished region. The horizontal dashed line represents a liquid level, shown here in the lower half of the tank. The radius of the dished head at the cross-section is x, or β in the dimensionless coordinates, and the liquid height at the cross section is h. We can normalize that liquid depth by defining a dimensionless variable, γ, as shown:

$$\gamma = h / D \qquad \textbf{(44)}$$

We relate h, d and x as follows:

$$= d - \left(\frac{D}{2} - x\right)$$

$$\text{here } \left(\frac{D}{2} - x\right) \le d \le \left(\frac{D}{2} + x\right) \qquad \textbf{(45)}$$

In other words, if the liquid depth is below $(D/2 - x)$, there is no liquid area at the cross-section, and if the depth is above $(D/2 + x)$, then the entire circular area is covered. Equation 45 can be written in terms of the dimensionless variables

$$\gamma = \delta - \frac{1}{2} + \beta$$

$$\text{where } \left(\frac{1}{2} - \beta\right) \le \delta \le \left(\frac{1}{2} + \beta\right) \qquad \textbf{(46)}$$

We can write an equation for the liquid area of a cross-section in the dished region (perpendicular to the main axis) by analogy to Equation 40, where the radius, x, replaces R, and where the liquid depth, h, replaces d.

$$A_{LD} = (h - x)\sqrt{2hx - h^2} + x^2 \sin^{-1} \frac{h - x}{x} + \frac{\pi x^2}{2} \qquad \textbf{(47)}$$

Next, we convert to dimensionless variables and substitute from Equation 46 to create Equation 48:

Equation 48: (see box, above) **(48)**

To get the liquid volume in the two dished tank heads, apply Equation 37:

$$v_{LD} = 2D\left[\int_0^{\alpha_1} A_{L1} d\alpha + \int_{\alpha_1}^{\alpha_2} A_{L2} d\alpha\right] \qquad \textbf{(49)}$$

If we were able to perform this integration and get a closed-form solution, we would substitute Equation 48 for A_{L1}, substitute for β in Region 1 from Equation 6 and perform similar substitutions for Region 2. That would give two integrals, each only involving the variable α. While it is not possible to perform those integrations analytically, it is possible to perform the integrations numerically.

We use Simpson's Rule for the numerical integration. It is based on having an odd number of equally spaced intervals in the independent variable, in this case α, and calculating the corresponding values for the areas. We chose to use 100 intervals between α = 0 and α = α_2. The numerical integration was performed as part of a spreadsheet, described below in the Results section. Simpson's Rule for any three consecutive integration points is

$$v_{LD} = \frac{2D(\Delta\alpha)}{3}\left(A_{La} + 4A_{Lb} + A_{Lc}\right) \qquad \textbf{(50)}$$

Where Δα is α_2/100 and A_{La}, A_{Lb}, and A_{Lc} are the areas at the three corresponding α points. The liquid volume in the two heads is calculated by applying Simpson's Rule to each of the three cross-sections, summing the parts to cover the 101 cross-sections, and doubling that to account for the two heads. The total liquid in the tank is the sum of the liquid in the cylindrical region and the two heads.

Liquid volume in true elliptical tank heads. Elliptical heads are commonly used on horizontal tanks. While a true ellipse doesn't conform to the definition of heads characterized by two radii of curvature, their shape is much simpler, and the contained liquid volume can be calculated by simple algebraic formula, derived below.

For this exercise we imagine an orthogonal x-y-z coordinate system with its origin at the center of an ellipsoid formed by revolving an ellipse about the z-axis. The z-axis is taken to coincide with the centerline of the cylindrical portion of the tank, and the x and y-axes are in the plane perpendicular to the z-axis at the center of the ellipsoid, with the y-axis being vertical. The equation that describes the surface of the ellipsoid is:

$$\frac{x^2}{R^2} + \frac{y^2}{R^2} + \frac{z^2}{Z^2} = 1 \qquad \textbf{(51)}$$

So, the x-axis intersects the ellipsoid at R, the y-axis intercepts at R, and the z-axis intercepts at Z. As an example, if one had a true 2:1 elliptical head, Z would equal R/2. We define e, the ratio of the intercepts of the ellipsoid, such that

$$Z = \frac{R}{e} = \frac{D}{2e} \qquad \textbf{(52)}$$

Straightforward integration shows that the area of an ellipse represented by Equation 53:

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1 \qquad \textbf{(53)}$$

is Equation 54 [*4*]:

$$A = \pi ab \qquad \textbf{(54)}$$

With the coordinate system described above for an ellipsoid, the y-axis will be the vertical axis, and the liquid surface will be perpendicular to that y-axis. All cross-sections perpendicular to that y-axis will intersect the ellipsoid as an ellipse in an x–z plane. Rearranging Equation 51 gives

$$\frac{x^2}{R^2\left(1 - \frac{y^2}{R^2}\right)} + \frac{z^2}{Z^2\left(1 - \frac{y^2}{R^2}\right)} = 1 \qquad \textbf{(55)}$$

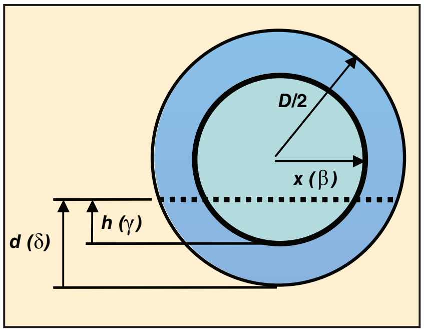

FIGURE 4. In this schematic view looking toward the left-hand dished head of a horizontal tank, the outer circle represents the cylindrical diameter and the inner circle represents a cross-section in the dished region

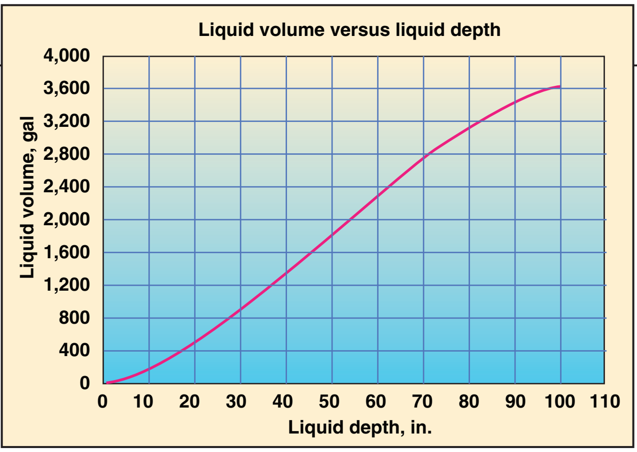

FIGURE 5. This plot shows the liquid volume versus liquid depth for an example horizontal tank

Comparing this with the general form of an ellipse in Equation 53, we see that the x-axis intercept of the ellipse in a plane perpendicular to the y-axis at any y value will be $R(1–{}^2/R^2)^{1/2}$. The corresponding z-axis intercept will be $Z(1–y^2/R^2)^{1/2}$. From Equation 54, the area of the ellipse will be

$$A = \pi RZ\left(1 - \frac{y^2}{R^2}\right) \tag{56}$$

To calculate the liquid depth in the two heads, we first recognize that the two heads combined comprise a complete ellipsoid. We calculate the liquid volume of both heads as

$$v_{LH} = \int_{-R}^{-R+d} A dy$$
$$= \pi RZ \int_{-R}^{-R+d}\left(1 - \frac{y^2}{R^2}\right)dy \tag{57}$$

Carrying out this integration and simplifying gives our final equation:

$$v_{LH} = \frac{\pi d^2}{3e}\left(\frac{3}{2}D - d\right) \tag{58}$$

For the case where $e = 1$, and heads are hemispherical, Equation 58 reduces to

$$v_{LH} = \frac{\pi d^2}{3}\left(\frac{3}{2}D - d\right) \tag{59}$$

If a tank with a hemispherical head is full ($d = D$), Equation 59 gives:

$$v_{LH} = \frac{\pi D^3}{6} \tag{60}$$

Which is the well-known formula for the volume of a sphere.

Equation 58 shows that the liquid volume (and capacity) of a true elliptical head is inversely proportional to e. Thus, for example, a true 2:1 elliptical head on a tank of a given diameter would hold exactly half the liquid volume of a hemispherical head on the same tank.

Results

The equations in this paper have been incorporated into two Microsoft Excel spreadsheets — one for vertical tanks and the other for horizontal tanks. Tables 4 and 5 show excerpts from the spreadsheet programs. (Note: Abbreviated versions of Tables 4 and 5 are shown on page here, while the full versions of both tables are available in the online version of this article at www.che.com, at the Web Extras tab.) The description of Tables 4 and 5 that follows pertains to the full website versions, but notations are made where the parts being discussed are not seen in the table excerpts that are shown in the print version here.)

The equations programmed in these spreadsheets are rather substantial. Considerable effort was expended to ensure accurate representation of the equations in the spreadsheet formulas. Readers may download the spreadsheet templates at www.che.com (Web Extras tab)..

A suggested organization would be to maintain one copy of each spreadsheet template, and then create a separate spreadsheet for each tank to which one wishes to apply the equations. So, an Excel Workbook might consist of the two spreadsheet templates, plus an individual spreadsheet for each physical tank of interest.

Below, the input parameters are identified, and the general layout of the spreadsheets is described. Then we show spreadsheet examples for a vertical tank (Table 4) and for a horizontal tank (Table 5). .For simplicity, the same tank (with different tank orientation) is used for both examples. The shaded cells are used to input the parameters for a specific vessel. The other cells are calculated by formulas.

The particular tank used in these examples has a dia. of 100-in. dia. (all dimensions are for the inside of the tank), a height or length of 120 in., and ASME F&D heads, designated as Head Style 1. The liquid has a specific gravity of 1.18.

The tank length specified in Tables 4 and 5 is the total length from end to end. It can be directly measured, allowing for the wall thickness, or determined from engineering drawings.

Some drawings may not give the overall length specifically. In these cases, the length of each head from the end to the plane where the head becomes cylindrical can be calculated by multiplying α_2 in Tables 4 or 5 by the inside tank diameter. If the drawing gives the distance between the weld beads, allowance must be made if the heads also include any cylindrical portion. If so, those lengths must be added to the length between the welds.

Four input parameters control the population of the strapping tables: (1) head style number; (2) tank diameter (in.); (3) tank length or height (in.); and (4) specific gravity of the liquid. They are entered in the top-left box in the shaded cells.

Below the input area is a box (not shown in the print version of the tables) containing head-style parameters calculated by the spreadsheet in accordance with the Head Style Number input. The values for α_1 to α_5 and f_d and f_k are supplied by formulas and are defined in the Nomenclature box.

The third box down on the left (titled Region Capacities in the print edition version of the tables) gives the calculated tank capacities for the five tank

NOMENCLATURE

Symbol	Description
a	x-axis intercept of an ellipse, Equation 53
A_L	Area of liquid in any cross-section perpendicular to the tank axis
b	y-axis intercept of an ellipse, Equation 53
C	Dimensionless proportionality constant in Equation 35
d	Liquid depth in the cylindrical region of a horizontal tank
D	Inside diameter of the cylindrical portion of tank
e	The ratio of the long to short axes of an ellipse of revolution
f_d	Dimensionless spherical radius
f_k	Dimensionless knuckle radius
h	Liquid depth at any cross-section in a dished head
H	Total inside tank height (vertical tank) or total inside tank length (horizontal tank)
R	Tank radius of cylindrical region
R_d	Radius of the spherical portion of a dished head
R_k	Radius of the knuckle curvature of a dished head
V_h	Volume of dished head
v_i	Volume of liquid in Region i
v_L	Liquid volume
V_i	Volume capacity of Region i
V_T	Volume capacity of the tank
x	Radial coordinate from the center line to the tank edge
y	Length coordinate from the bottom of the tank (vertical tank) or the left-hand end of the tank (horizontal tank)
z	Z-axis of an orthogonal coordinate system
Z	Z-axis intercept of an ellipsoid; height of a true elliptical head

Symbol	Description
α	Dimensionless height (vertical tank) or length (horizontal tank)
β	Dimensionless radius
δ	Dimensionless liquid depth in the cylindrical region of a horizontal tank
$\Delta\alpha$	Dimensionless interval in Simpson's Rule
γ	Dimensionless liquid depth at any cross-section in a dished head
θ	Angle between the tank center line and a radius drawn from the origin of the spherical radius of a torispherical head through the origin of the knuckle radius
Subscripts	
a	First cross-section in the Simpson's Rule formula
b	Second cross-section in the Simpson's Rule formula
c	Third cross-section in the Simpson's Rule formula
C	Cylindrical region of the tank
d	Spherically shaped dished head region
H	Both elliptical heads combined
k	Center point of the knuckle radius
L	Liquid
1	Plane where the bottom or left spherical region meets the adjacent knuckle region; bottom or left spherical region
2	Plane where the bottom or left knuckle region meets the cylindrical region; bottom or left knuckle region
3	Plane where the cylindrical region meets the top or right knuckle region; cylindrical region
4	Plane where the top or right knuckle region meets the adjacent spherical region; top or right knuckle region
5	Top or right-hand end of the tank; top or right spherical region

TABLE 4. STRAPPING TABLE FOR A VERTICAL TANK

Input Information	
Tank name:	T-1000
Tank orientation	Vertical
Liquid	Aq. solvent
Head style	1
Tank dia., in.	100.0
Tank height, in.	120.0
Specific gravity	1.18

Region Capacities	Gal.
V_1	176.9
V_2	173.8
V_3	2,928.5
V_4	173.8
V_5	176.9
V_T	3,629.8

Depth	Liq. depth		Liq. depth	Liq. vol.	Weight
gage: %	ft	in.	in.	gal	lb
0	0	0	0	-	-
*					
10	1	0	12	188	1,850
*					
33	3	4	40	1,135	11,166
*					
100	10	0	120	3,630	35,713

* Rows not shown in this abbreviated version of this table can be found in the full version online.

Liquid Volume Calculator	
(This calculator will return the liquid volume for an input liquid level.)	
Liq. depth, in. =	12.0
α =	0.120
Liq. vol., gal =	187.99

regions and for the total tank. Below that (not shown in the print version) is a lookup table that gives parameters for the various head styles. Specifying a Head Style Number in the Input Information Box pulls the appropriate values for f_d, f_k, α_1, and α_2 from this lookup table and places them in the Head Style Parameter box (not shown in the print version of these tables).

The Head Style Number, one of the required input parameters, is defined in the box just below the strapping table (again, not shown in the print version). Five choices are offered for vertical tanks and a sixth one is added for horizontal tanks. That sixth style is for a true elliptical head. If that style is chosen, then the value for the True Ellipse Ratio must be entered in the box below the strapping table. It is the ratio of the long axis to the short axis of the true-elliptical head. Most elliptical heads are fabricated using two radii of curvature to approximate the ellipse.

Different manufacturers use somewhat different radii in their approximations. The spreadsheet offers a choice between using a two-radii approximation (Style 4) or a true ellipse (Style 6). These two options might be useful if one wanted to compare how close the two radii approximation is to a true ellipse. If one had elliptical heads with f_d and f_k values other than used here for Head Style 4, one could simply enter those values in the box below the strapping table for Head Style 4.

The large tables displayed as two panels in the upper center and upper right of Tables 4 and 5 are the strapping tables (abbreviated in the print version). There, a liquid volume and a liquid weight (calculated from the liquid density input) is shown for each 1% of the total possible liquid depth range. The 1% liquid depth increments are expressed as (1) percentages, (2) as ft and in., and (3) as in. Then each row gives the calculated liquid volume in gal and weight in lb. If one has a liquid depth that falls between two rows in the strapping table, one can interpolate. Or, a plot of the table could be constructed and used to read the volume. Or, the Liquid Volume Calculator can be used, described as follows.

At the bottom of each spreadsheet is what is called the Liquid Volume Calculator. It uses the input parameters described above along with a liquid level entered in the Liquid Volume Calculator. That value can be as exact as one cares to specify it. The Liquid Volume Calculator then calculates the

TABLE 5. STRAPPING TABLE FOR A HORIZONTAL TANK

Input Information	
Tank name	T-1001
Tank orientation	Horizontal
Liquid	Aq. solvent
Head style	1
Tank dia., in.	100.0
Tank length, in.	120.0
Specific gravity	1.18

Depth	Liq. depth		Liq. depth	Liq. vol.	Weight
gage, %	ft	in.	in.	gal	lb
0	0	0	0	-	-
*					
40	3	4	40	1,338	13,160
*					
50	4	2	50	1,815	17,856
*					
100	8	4	100	3,630	35,713

* Rows not shown in this abbreviated versiono of this table can be found in the full version online.

Region	
Capacities	Gal
V_1	176.9
V_2	173.8
V_3	2,928.5
V_4	173.8
V_5	176.9
VT	3,629.8

Liquid Volume Calculator	
(This calculator will return the liquid volume for an input liquid level.)	
Liq. depth, in. =	50.0
Liq. vol. cyl., gal =	1,464.25
Liq. vol. heads, gal =	350.65
Liq. vol., gal =	1,814.89

liquid volume for that liquid level.

Vertical tank orientation. Table 4 (abbreviated here) shows the spreadsheet output for the above-described tank oriented vertically. The total tank capacity is 3,629.8 gal, with 80.7% of that being in the cylindrical region (2,928.5 gal) and the rest being in the two heads. If one wanted to know the liquid volume for liquid depth of 40 in., for example, a table lookup would give 1,135 gal or 11,166 lb. To illustrate the Liquid Volume Calculator a liquid level of 12.0 in. was entered, which returned a liquid volume of 187.99 gal. That volume corresponds to the value in the strapping table.

Horizontal tank orientation. Table 5 (abbreviated here) displays the same tank oriented horizontally. The tank capacities of the five regions and the total tank capacity are the same as in Table 4. The difference in this spreadsheet is that the strapping table must be populated using numerical integration (Simpson's Rule) for the liquid volumes in the heads because of the complexity of the equation being integrated. That integration is performed in spreadsheet cells below those shown in Table 5 (only shown in the Excel spreadsheets available for download), with the results of the integration being carried up to the appropriate line in the Liquid Volume Calculator.

An Excel macro populates each row in the table by repeatedly carrying out the following steps: (1) copies a liquid level from the strapping table to the clipboard; (2) pastes that value into the Liquid Volume Calculator which allows the Simpson's Rule integration to be performed and the result placed in the appropriate row of the Liquid Volume Calculator; (3) copies the total liquid volume from the Liquid Volume Calculator to the clipboard;

and (4) pastes the total liquid volume from the Liquid Volume Calculator to the appropriate row of the strapping table. The macro repeats that operation for each line of the table.

After one enters these parameters for a particular tank, clicking the "Click to Run Macro to Populate" button activates the macro and populates the liquid volumes in the table. It will be necessary to enable macros in Excel if that functionality has been disabled for security reasons.

In the Simpson's Rule integration (only shown in the spreadsheets for download), the dished head is partitioned by 101 equally spaced planes perpendicular to the tank's main axis. A liquid area is calculated for each plane, and the integration is performed by Simpson's Rule to give a liquid volume for the specified depth.

So, for example, if one had a liquid height of 40 in. in the described horizontal tank, a lookup in Table 5 would give a liquid volume of 1,338 gal and a liquid weight of 13,160 lb. The Liquid Volume Calculator at the bottom of the spreadsheet works the same way as described for the vertical tank. In this example, a liquid height of 50.0 in. was entered and a corresponding liquid volume of 1,814.89 gal was returned. Figure 5 shows a plot of the liquid volume versus depth for this example. ■

Edited by Suzanne Shelley

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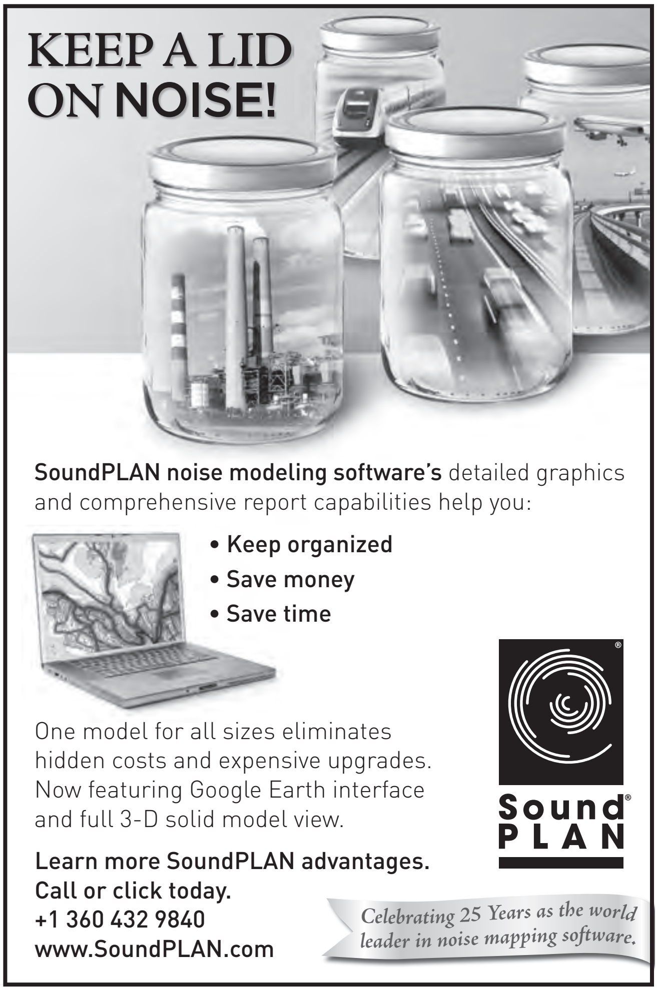

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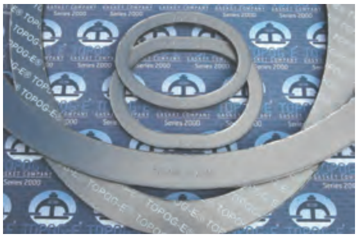

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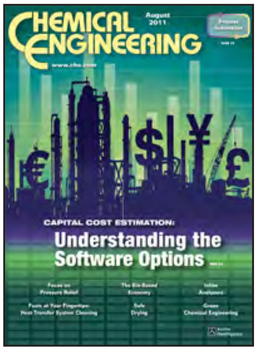

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BUSINESS NEWS

PLANT WATCH

Solvay to form JV with Sadara to build H_2O_2 plant in Saudi Arabia

July 28, 2011 — Solvay S.A. (Brussels, Belgium; www.solvay.com) intends to create a 50:50 joint venture (JV) with Sadara Chemical Co. (itself a planned JV of Saudi Arabian Oil Co. and The Dow Chemical Co. — see below) for the construction and operation of a hydrogen peroxide plant in Jubail Industrial City. Scheduled to be operational in the 2nd half of 2015, this new plant will supply H_2O_2 as a raw material for the manufacture of propylene oxide by Sadara.

Lubrizol invests in expansion at Louisville production plant

July 27, 2011 — Lubrizol Advanced Materials, a business segment of The Lubrizol Corp. (Wickliffe, Ohio; www.lubrizol.com) has begun work on a multimillion-dollar expansion at its Louisville, Ken., manufacturing facility in order to meet growing demand for its chlorinated polyvinyl chloride products. The expansion effort is expected to continue through 2012.

BASF plans second production plant for phthalate-free plasticizer

July 26, 2011 — BASF SE (Ludwigshafen, Germany; www.basf.com) is planning to build a second production plant in Ludwigshafen to double production of its phthalate-free plasticizer from 100,000 to 200,000 metric tons per year (m.t./yr) at the site by 2013.

Dow and Saudi Aramco form JV for a $20-billion chemicals complex

July 25, 2011 —The Dow Chemical Co. (Midland, Mich.; www.dow.com) and the Saudi Arabian Oil Co. (Dhahran, Saudi Arabia; www.saudiaramco.com) have approved the formation of a JV, named Sadara Chemical Co., to build and operate a chemicals complex in Jubail Industrial City, Kingdom of Saudi Arabia. Comprised of 26 manufacturing units, the complex will be one of the world's largest integrated chemical facilities, and the largest ever built in one single phase. The complex will possess flexible cracking capabilities and will produce over 3 million m.t. of high-value-added chemical products and performance plastics. The first production units will come on line in the 2nd half of 2015, with all units expected to be up and running in 2016. Sadara will become an equal JV between Saudi Aramco and Dow after an initial public offering.

Occidental Chemical Corp. plans to build a chlor-alkali plant in Tennessee

July 21, 2011 — Occidental Chemical Corp. (Oxychem; Dallas, Tex.; www.oxychem.com), a subsidiary of Occidental Petroleum Corp., plans to construct a membrane cell chlor-alkali plant adjacent to DuPont's Johnsonville TiO_2 plant in Tennessee. The new facility will be designed to produce up to 182,500 ton/yr of liquid chlorine and 200,000 dry ton/yr of membrane caustic soda. Operation is expected to begin in 2013. The project cost is estimated at $250–290 million. Final execution of the project is dependent upon a final review of the project's economic feasibility.

SGL Group breaks ground for a new graphite-production center in Bonn

July 19, 2011 — SGL Group – The Carbon Company (Wiesbaden, Germany; www.sglgroup.com) is planning a new 3,500-m^2 production center for isostatic graphite. Construction is scheduled to start this month, with completion planned by the end of 2012. As a result, SGL Group's capacity for isostatic graphite will be increased from 5,000 to 15,000 ton/yr worldwide.

New pulp mill in Uruguay to be supplied by ABB

July 11, 2011 — ABB (Zurich, Switzerland; www.abb.com) will supply process electrification, power distribution infrastructure and equipment for a new pulp mill in Uruguay. The Montes del Plata pulp mill is a joint project of Finnish pulp and paper manufacturer, Stora Enso, and the Chilean forestry company, Arauco, and has an estimated cost of $1.9 billion. Production is scheduled to be begin in the 1st Q of 2013, with a capacity of 1.3 million m.t./yr of bleached, eucalyptus kraft pulp. The project includes the pulp mill, a deepwater port and a biomass-based power generation plant to convert waste from pulp production into electricity.

M&G Group selects Texas for new PET and PTA plants

July 12, 2011 —The M&G Group (Tortona, Italy; www.gruppomg.com), has selected Corpus Christi, Tex., as the location for construction of its previously announced 1-million m.t./yr polyethylene terephthalate (PET) and accompanying 1.2-million m.t./yr purified terephthalic acid (PTA) plants.

Axens-Viscolube Revivoil technology selected for NexLube's oil re-refining plant

July 11, 2011 — NexLube Tampa LLC plans to construct a used oil, re-refinery and blending plant in Tampa, Fla. using Axens' (Rueil-Malmaison, France; www.axens.net) and Viscolube S.p.A.'s (Pieve Fissiraga, Italy; www.viscolube.it) Revivoil technology. The facility is expected to process 24 million gal/yr of dehydrated used oil to produce API Group II base oil and various grades of motor oil, hydraulic fluid, transmission fluid and other specialty products after blending.

MERGERS AND ACQUISITIONS

Ownership structure changes in Sabina Petrochemicals JV

August 1, 2011 – BASF Corp. (Florham Park, N.J.; www.basf.us) and Total Petrochemicals USA, Inc. (Houston; www.totalpetrochemicalsusa.com) have announced a change in ownership of the Sabina Petrochemicals LLC JV that operates one of the world's largest C4 complexes, which is located in Port Arthur, Tex. Shell Chemical LP, has exited the JV. BASF and Total Petrochemicals are now the sole partners in Sabina with 60:40 ownership shares. BASF will continue to operate the Sabina plants. The terms of the agreement are confidential.

BASF and CSM explore a bio-based succinic acid JV

August 1, 2011 — BASF SE (Ludwigshafen, Germany; www.basf.com) and Purac (Gorinchem; www.purac.com), a subsidiary of CSM N.V. (Diemen, both the Netherlands; www.csm.nl) are negotiating the formation of a JV for the production of bio-based succinic acid. They aim to have a 25,000-ton capacity fermentation production plant at the Purac site near Barcelona, Spain, with the intention to start up by 2013.

AkzoNobel to acquire China's leading specialty surfactant producer

July 27, 2011 — AkzoNobel (Amsterdam, the Netherlands; www.akzonobel.com) plans to acquire Boxing Oleochemicals, the leading supplier of nitrile amines and derivatives in China and throughout Asia. Established in 1993 and based in the province of Shandong, Boxing had revenues in 2010 of approximately €100 million. Its activities will be integrated into AkzoNobel's Surface Chemistry business. The completion of the transaction is subject to closing conditions, including the approval of the Chinese authorities. It is expected to be finalized in the last quarter of 2011. ■

Dorothy Lozowski

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

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Economic Indicators

2009 🟧 2010 🟪 2011 🟦

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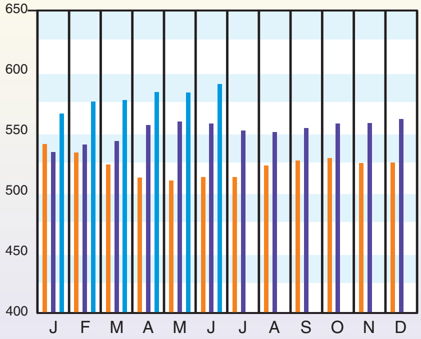
CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957-59 = 100)	June '11 Prelim.	May.'11 Final	June '10 Final
***CE* Index**	588.9	581.9	556.4
Equipment	718.1	707.5	668.1
Heat exchangers & tanks	678.1	673.0	628.7
Process machinery	664.5	663.7	632.1
Pipe, valves & fittings	904.8	861.8	818.5
Process instruments	440.9	441.8	419.4
Pumps & compressors	904.7	905.4	898.4
Electrical equipment	510.8	503.0	482.2
Structural supports & misc	760.7	755.7	697.5
Construction labor	325.4	325.2	326.7
Buildings	519.0	518.6	509.4
Engineering & supervision	332.6	332.9	339.1

Annual Index:

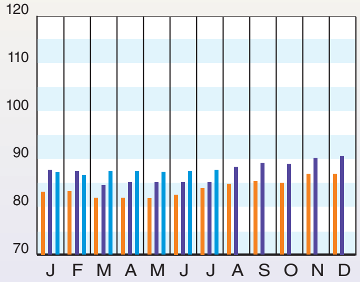
2003 = 402.0
2004 = 444.2
2005 = 468.2
2006 = 499.6
2007 = 525.4
2008 = 575.4
2009 = 521.9
2010 = 550.8



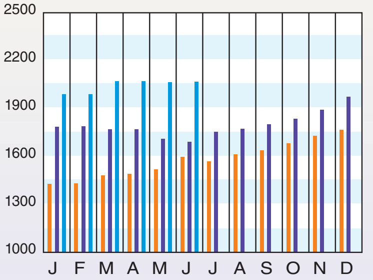
CURRENT BUSINESS INDICATORS

	LATEST			PREVIOUS						YEAR AGO		
CPI output index (2007 = 100)	Jul.'11	=	87.7	Jun.'11	=	87.4	May.'11	=	87.3	Jul.'10	=	85.1
CPI value of output, $ billions	Jun.'11	=	2,067.0	May.'11	=	2,065.1	Apr.'11	=	2,072.8	Jun.'10	=	1,691.3
CPI operating rate, %	Jul.'11	=	75.6	Jun.'11	=	75.3	May.'11	=	75.3	Jul.'10	=	72.9
Producer prices, industrial chemicals (1982 = 100)	Jul.'11	=	338.0	Jun.'11	=	342.6	May.'11	=	336.0	Jul.'10	=	257.8
Industrial Production in Manufacturing (2007=100)	Jul.'11	=	90.6	Jun.'11	=	90.0	May.'11	=	89.9	Jul.'10	=	87.3
Hourly earnings index, chemical & allied products (1992 = 100)	Jul.'11	=	158.8	Jun.'11	=	156.9	May.'11	=	157.0	Jul.'10	=	153.6
Productivity index, chemicals & allied products (1992 = 100)	Jul.'11	=	112.3	Jun.'11	=	112.1	May.'11	=	111.0	Jul.'10	=	111.8

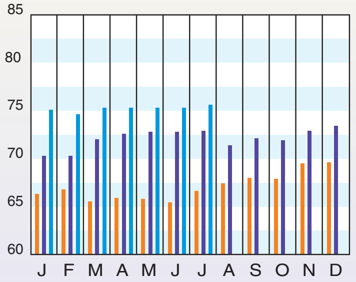
CPI OUTPUT INDEX (2007 = 100)



CPI OUTPUT VALUE ($ BILLIONS)



CPI OPERATING RATE (%)



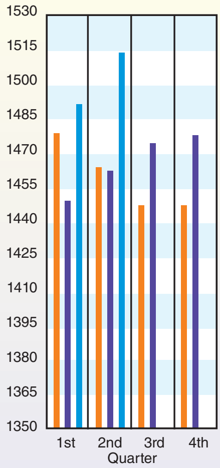
Current Business Indicators provided by Global Insight, Inc., Lexington, Mass.

MARSHALL & SWIFT EQUIPMENT COST INDEX

(1926 = 100)	2nd Q 2011	1st Q 2011	4th Q 2010	3rd Q 2010	2nd Q 2010
M & S INDEX	1,512.5	1,490.2	1,476.7	1,473.3	1,461.3
Process industries, average	1,569.0	1,549.8	1,537.0	1,534.4	1,522.1
Cement	1,568.0	1,546.6	1,532.5	1,530.0	1,519.2
Chemicals	1,537.4	1,519.8	1,507.3	1,505.2	1,493.5
Clay products	1,557.5	1,534.9	1,521.4	1,518.3	1,505.6
Glass	1,469.2	1,447.2	1,432.7	1,428.5	1,416.4
Paint	1,584.1	1,560.7	1,545.8	1,542.1	1,527.6
Paper	1,480.7	1,459.4	1,447.6	1,444.5	1,430.1
Petroleum products	1,672.0	1,652.5	1,640.4	1,637.0	1,625.9
Rubber	1,617.4	1,596.2	1,581.5	1,579.3	1,564.2
Related industries					
Electrical power	1,494.9	1,461.2	1,434.9	1,419.2	1,414.0
Mining, milling	1,623.5	1,599.7	1,579.4	1,576.7	1,569.1
Refrigeration	1,856.4	1,827.8	1,809.3	1,804.8	1,786.9
Steam power	1,546.5	1,523.0	1,506.4	1,502.3	1,488.0

Annual Index:

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

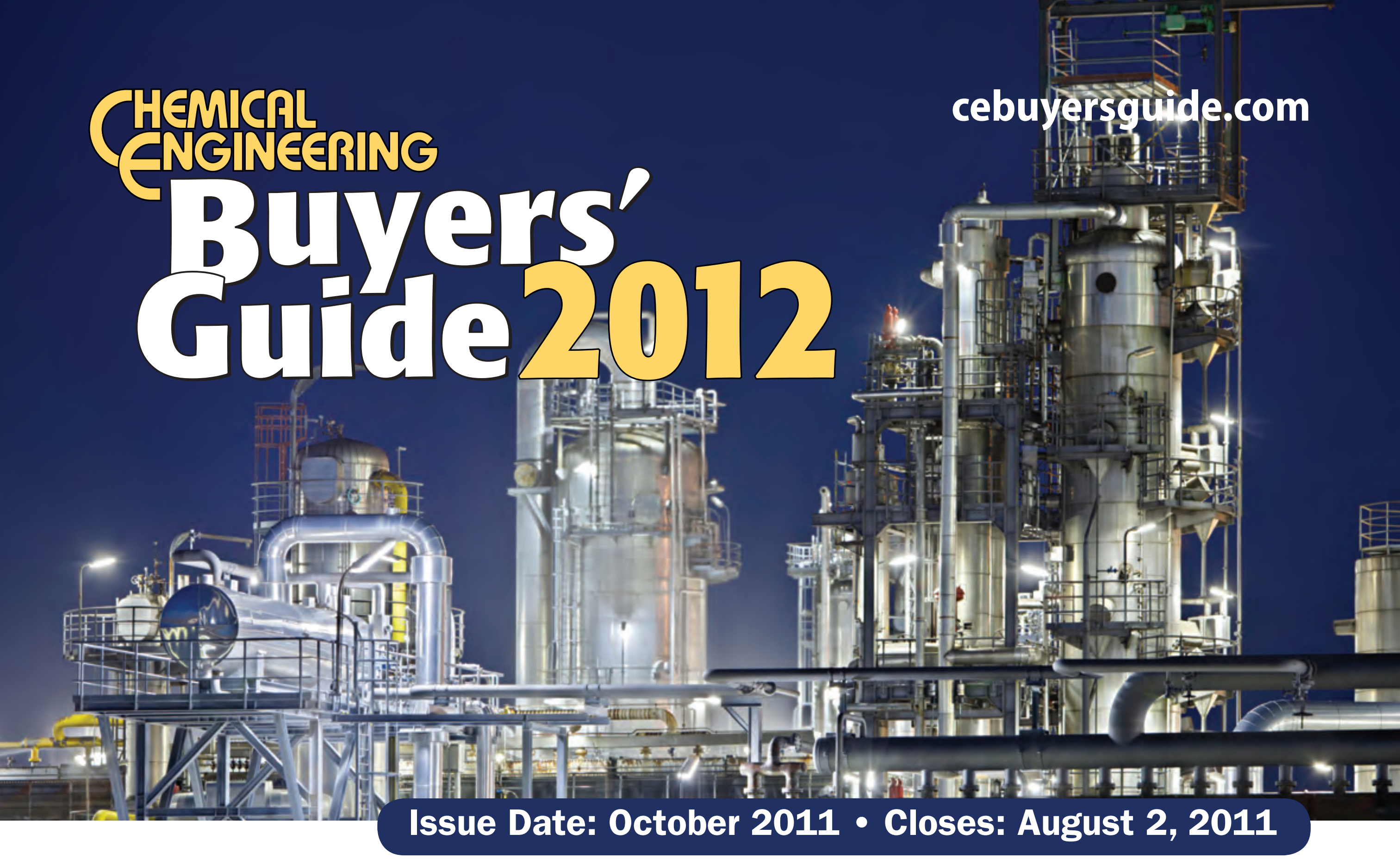


CURRENT TRENDS

Capital equipment prices, as reflected in the *CE* Plant Cost Index (CEPCI), increased approximately 1.2% on average from May to June, after decreasing approximately 0.10% from April to May.

Meanwhile, according to the American Chemistry Council's (Washington, D.C.; www.americanchemistry.com) latest weekly economic report, overall production in the U.S. chemical sector fell in July by 0.3%, to continue an uneven pattern in 2011.

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



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