CHEMICAL ENGINEERING

January 2010

www.che.com

Wastewater Treatment

PAGE 34

Boosting Catalyst Productivity

Pipe Sizing Rules

Focus on Weighing

Audiosonic Acoustic Cleaners

Recognizing Your Colleagues

DESIGN DECISIONS:

Don't Leave Economics to Chance

PAGE 26

Pressure Relief Systems

Facts At Your Fingertips: Low-Pressure Measurement

Newest Scrubbing Technologies

Access Intelligence

CHEMICAL ENGINEERING

www.che.com

COVER STORY

NEWS

ENGINEERING

EQUIPMENT & SERVICES

COMMENTARY

DEPARTMENTS

ADVERTISERS

COMING IN FEBRUARY

Look for: **Feature Reports** on Doing an Energy Audit; and Distillation Debottlenecking; an **Environmental Manager article** on Electronic Valve Actuators: an **Engineering Practice article** on Selecting Variable Frequency Drives for Centrifugal Pumps; **Focus** on Mixers; **News articles** on Supercritical carbon dioxide; and Engineering Software; **Facts at Your Fingertips** on Pumps; and more

Cover: David Whitcher

More than 100,000 customers in every industry around the globe trust Endress+Hauser to make their processes safe, efficient and repeatable. Just like a puzzle, many pieces must come together at the right time and place to manufacture a product profitably. Endress+Hauser understands there is a world of difference between a good fit and a perfect fit for your critical process measurement needs. This is evidenced by the hundreds of thousands of instruments we deliver every year worldwide – the widest range available from any one supplier. When you need support with planning, engineering, project management, automation, or just need help with a difficult process, Endress+Hauser is the partner you can depend on.

Endress+Hauser, Inc
2350 Endress Place
Greenwood, IN 46143
inquiry@us.endress.com
www.us.endress.com

Sales: 888-ENDRESS
Service: 800-642-8737
Fax: 317-535-8498

Endress+Hauser
People for Process Automation

Circle 06 on p. 62 or go to adlinks.che.com/29246-06

Editor's Page

New HART award aims to spark progress across the CPI

Number six on this magazine's list of twelve tips for clearer technical writing is "When writing about concepts that are new, unfamiliar or abstract, try to include examples." This principle, as articulated in an informative article by former *CE* Editor-in-Chief Nicholas P. Chopey (*CE*, July 2003, pp. 73–75), is admittedly simple but can nevertheless be pivotal. Without effective examples, it would take many innovative solutions far too long to saturate their intended outlet and reach their full potential.

With that reality in mind, *CE* has the exclusive media privilege of unveiling that the Evonik Degussa GmbH (Essen, Germany; www.evonik.com) Methacrylates Complex, at the Multi User Site (MUSC) in Shanghai's Chemical Industry Park, has been selected as the winner of the HART Innovative Achievement Award. The new award is presented by the HART Communication Foundation (HCF; Austin; www.hartcomm.org) in recognition of exceptional achievement, ingenuity and innovation in using HART communication in realtime applications to improve operations and maintenance. The project and the award itself illustrate how the CPI's pioneers can both inspire and be inspired by winning technological applications.

Although the HART communication protocol is certainly not new, its full capabilities can seem abstract to chemical engineers whose process control training is too often limited to Laplace transforms or basic control theory. Even for engineers who have practical control-system training and experience, the widescale adoption of HART — or any other communication bus, for that matter — is much easier to visualize and justify with the help of compelling success stories.

Indeed, the Shanghai facility's achievement begins with yet another example. At the start of its project, Evonik read an application story posted on the HART Website about how a BP facility saved money installing smart valve positioners to help identify which valves needed to be repaired during plant shutdowns. Before the use of HART to identify valve conditions at BP, a certain number of valves were removed and repaired at every shutdown, whether the valve actually needed repair or not.

Evonik then decided to design-in the use of HART to help reduce its own maintenance costs and now has over 2,000 HART-compatible instruments and valves from multiple global manufacturers. "Our technician can now quickly and more efficiently access device calibration, integrity and wiring information in order to check that the entire control loops are performing according to the process design," says the plant representative. "As a direct result of this implementation, we managed to cut loop-check time and costs by 25% compared to the traditional method based on conventional handheld devices. As well, daily troubleshooting of instruments is now mainly performed from the safety and convenience of the control room."

The team is now initiating a predictive maintenance program, in which priority equipment such as key control valves and safety instruments receive immediate attention. "Once they experienced first-hand the power, performance and reliability of HART technology, they decided to use HART in additional applications.," says Ed Ladd, HCF director of Technology Programs. "This application is a model for new plants of all types — that HART is the right communication choice to lower maintenance and operation costs."

We invite you to visit www.che.com for more about the award and this exemplary application. ■

Rebekkah Marshall

Letters

Underground storage tanks

November 2009, Facts At Your Fingertips "Aboveground and Underground Storage Tanks": It is articles like this one that cause me a major headache. Our company deals in assisting clients with their regulatory compliance. When I see a client who has an underground tank my first question is "Why?". The answer is "We need the above ground space." There is a third option, overlooked by most and that is to place the tank in a vault. The result is that the tank is regulated as an above ground tank, with all of the advantages of an underground tank. Their next comment is, "But no one told me." Yes, the initial cost is a little more, but the savings over the long run are considerable.

George Moczulski
Ambient Engineering

Help transform the energy landscape

Do you have an idea to transform the energy landscape by a 10x Engineering Factor? The American Institute of Chemical Engineers' (AIChE) 10xE Competition is open for you to realize your idea potential.

Submit your concept to Alan Fuchs and Alok Pradhan by January 31, 2010, at: 10xE@aiche.org

The 10xE competition will focus on radically efficient designs of processes and devices that dramatically reduce energy and resource consumption. The submitted concepts should focus on capturing the methodology behind radically efficient designs of processes, devices and materials and highlight the results.

All can participate. Entrepreneurial teams as well as individual engineers will submit case study papers of their designs and the top entries will be announced at the Energy Efficiency Plenary by Amory Lovins during the AIChE Spring Meeting, March 23, 2010, San Antonio, Tex.

An expert judging panel lead by Amory Lovins of the Rocky Mountain Institute will select the winning papers.

The winning concepts will receive the following awards and recognition:

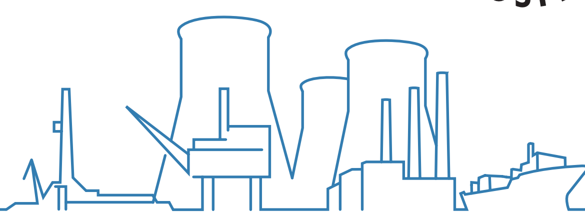
- Free AIChE Spring Meeting registration
- An AIChE Energy Efficiency Award Certificate
- Case study review by Amory Lovins at the Energy Efficiency Plenary
- Press coverage
- Publication in RMI 10xE Casebook

In addition, review by investors is planned and a limited number of travel stipends will be made available.

To learn more about the challenge, visit www.aiche.org/Energy/GetInvolved/10xEChallenge.aspx

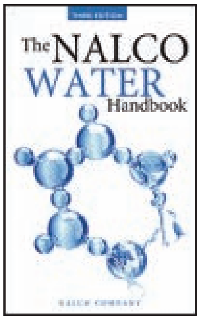
Postscripts, corrections

December 2009, Focus on Level Measurement and Control, pp. 51–53: On p. 52, the Website address for Tecmark Corp. was listed incorrectly. The correct address is www.tecmarkcorp.com. ■



Circle 08 on p. 62 or go to adlinks.che.com/29246-08

Bookshelf



The Nalco Water Handbook, 3rd ed. By Daniel Flynn. McGraw Hill Co., 1221 Avenue of the Americas, New York, NY 10121. Web: www.mcgrawhill.com. 2009. 1,280 pages. $125.00.

Reviewed by Brad Buecker,
Technical support specialist,
AEC PowerFlow, Kansas City, Mo.

The third edition of Nalco's comprehensive manual on water and water treatment is an effective replacement to the previous version as well as an excellent information source for those seeking to learn about industrial water treatment and improve plant operation and efficiency. The opening section covers fundamental water chemistry, and provides useful information for plant personnel who may encounter a steep learning curve with regard to industrial water treatment.

Section 2 includes chapters on the removal of impurities from raw water makeup and conditioning of the water to minimize corrosion, scaling or other problems downstream. The section contains a comprehensive discussion of water clarification and multimedia filtration — technologies that have been the backbone of primary water pretreatment for years — as well as discussions of ion exchange and membrane separation technologies. Although the order of the chapters could have been reversed, the ion exchange chapter contains much useful information, including a good discussion of how primary exchange resins function.

The three pages devoted to micro- and ultra-filtration may not be enough, given the potential for these systems to replace clarifiers and sand filters in many applications. Discussion of reverse osmosis, which has proven to be an excellent pretreatment technology, was comprehensive.

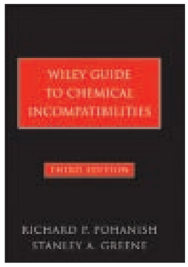
A portion of the section covers the widely utilized process of steam generation in detail, and includes an informative discussion on a number of industrial boiler designs. A chapter on boiler feedwater treatment focuses on deposits that foul steam generators, and ways to prevent scaling and fouling. A short chapter on turbines is a new and welcome addition to the book, given turbines' integral role in power generation and wide use at other industrial plants. Another chapter investigates problems that can be caused by oxygen and carbon dioxide in condensate return systems, which can be relatively complex for industrial applications.

Section 2.3 is devoted to cooling water processes and chemistry. Chapter 14 offers a good review of the types of cooling water systems, with much discussion on open recirculating systems that use cooling towers. Notable are useful chapters on mechanisms of fouling and corrosion, others on cooling water system monitoring, as well as several chapters on cooling water biology.

A major portion of the book addresses wastewater treatment, a complex process that is handled in an informative manner. An outline of wastewater system designs and treatment methods is followed by a helpful discussion of dissolved air flotation as well as the removal of ammonia, phosphorous, suspended solids, and heavy metals from wastewater. The material on reclaimed water could have been expanded to include water reuse, given its increasing importance. The section concludes with chapters on sludge disposal, emulsions and wet scrubbing of gases.

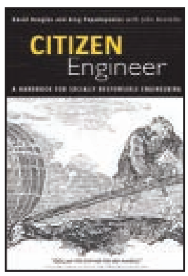
Section 3 is devoted largely to reducing energy usage, through lower electric use in motors and other equipment, as well as improved aeration and process upgrades.

The third edition wisely retains a set of industry-specific chapters that appeared in earlier versions of the book. The set includes chapters on the paper, power, chemical, petroleum, aluminum, steel, coal, food and municipal water industries.

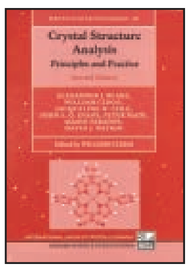


Wiley Guide to Chemical Incompatibilities. 3rd ed. By Richard P. Pohanish and Stanley A. Greene. Wiley & Sons Inc., 111 River St., Hoboken, NJ 07030. Web: www.wiley.com. 2009. 1,110 pages. $175.00.

The Science and Engineering of Cutting. By Tony Atkins. Butterworth-Heinemann, 30 Corporate Dr., Suite 400, Burlington, MA. 01803. Web: www.elsevier.com. 2009. 432 pages. $64.95.

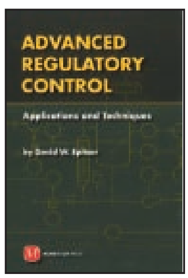


Citizen Engineer: A Handbook for Socially Responsible Engineering. By David Douglas, Greg Papadopoulos and John Boutelle. Prentice Hall, One Lake St., Upper Saddle River, NJ 07458. Web: www.prenhall.com. 2009. 292 pages. $27.00.



Effective Alarm Management System Practices. By The ASM Consortium. CreateSpace, 100 Enterprise Way, Suite A200, Scotts Valley, CA 95066. Web: www.createspace.com. 2009. 106 pages. $150.00.

Crystal Structure Analysis: Principles and Practice, 2nd ed. By Alexander Blake and others. Oxford University Press Inc., 198 Madison Ave., New York, NY 10016. Web: www.oup.com/us. 2009. 387 pages. $59.95.



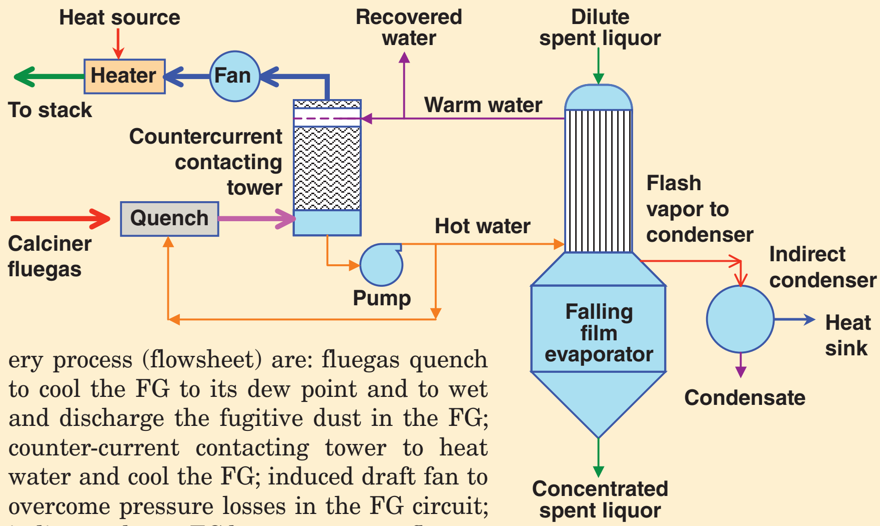
Design for Environment: A Guide to Sustainable Product Development, 2nd ed. By Joseph Fiksel. McGraw Hill Co., 1221 Avenue of the Americas, New York, NY 10121. Web: www.mcgrawhill.com. 2009. 410 pages. $125.00.

Advanced Regulatory Control: Applications and Techniques. By David Spitzer. Momentum Press LLC, 222 East 46th Street, New York, NY 10017. Web: www.momentumpress.net. 2009. 145 pages. $49.95. ■

Scott Jenkins

"In the auto industry, no one drives faster than Uniseal."
Uniseal is known throughout the OEM auto industry as a premier supplier of structural adhesive and sealant systems. With fast-moving R&D, custom formulations and superb quality, it's easy to see why this company has been so successful.
To keep production in the passing lane, Uniseal relies on the finest equipment available anywhere for high-viscosity vacuum mixing: 10- to 1,500-gallon double planetary and triple-shaft mixers engineered right here at Ross.
We'd like to help you succeed, too. Call 1-800-243-ROSS. Or visit www.mixers.com.
Circle 10 on p. 62 or go to adlinks.che.com/29246-10
UNISEAL
Tom DiGiannurio, Senior Engineer, Ross Employee Owner
ROSS

Recovering energy from fluegas



Alcoa of Australia (www.alcoa.com.au) has developed a process to recover sensible and latent heat from the fluegas (FG) produced by Bayer alumina calciners, and use the heat to evaporate Bayer spent liquor. Peter Hay, of Alcoa's Technology Delivery Group, at Alcoa's Kwinana Refinery, in Western Australia, says the recovered heat can also be applied to seawater desalination. Calcination consumes 25 to 40% of the refinery's total energy input, and produces large quantities of FG that is generally vented to the atmosphere, says Hay.

Energy is recovered from the FG by progressive cooling. Only sensible heat is recovered between 165°C and the dew point. Below the dew point, the energy recovered is mainly the latent heat of the water condensed. The higher-grade, sensible heat is only about 10% of the practical recoverable energy, considering 50°C to be the heat sink practical limit. Water is recovered after the dew point is reached. Since considerable refining infrastructure is invested to collect and store fresh water — an essential raw material for the Bayer process — any process that can reduce fresh water usage has significant value to the refining operation, says Hays.

The basic components of the heat recovery process (flowsheet) are: fluegas quench to cool the FG to its dew point and to wet and discharge the fugitive dust in the FG; counter-current contacting tower to heat water and cool the FG; induced draft fan to overcome pressure losses in the FG circuit; indirect exhaust FG heater to ensure fluegas buoyancy and dispersion; falling film evaporator, to exchange heat between the heated water in the shell with the spent liquor film flowing inside the tubes thereby evaporating the spent liquor; and indirect heat exchanger, to condense and recover high quality condensate from the evaporated liquor.

For every metric ton (m.t.) of smelting-grade alumina produced, about 0.2 GJ of sensible heat is recovered from FG exit temperatures between 85 and 165°C, and about 0.6 m.t. of water is recovered from FG exit temperatures between 57 and 82°C. Hay and co-inventor Dean Ilievski, also of Alcoa's Technology Delivery Group, have applied for a patent on the process.

Large-diameter reverse osmosis product lowers cost and reduces footprint

Koch Membrane Systems Inc. (KMS; Wilmington, Mass.; www.kochmembrane.com) recently unveiled large-diameter reverse osmosis (RO) elements and pressure vessels for seawater desalination that offer cost savings and reduced footprints. The new RO element and pressure vessel combinations have an 18-in. dia. and a 60-in. length, rather than the standard 8-in.-dia., 40-in.-long size that has been commonly used. The larger size translates to an effective membrane area of 17,500 ft^2 per vessel, compared to 2,800 ft^2 for conventional 8-in. elements.

"The larger diameter becomes cost-effective at capacities of around 1-million gal/d," says Imran Jaferey, Koch's vice-president for water and wastewater. "Once capacities get into the range of tens of millions of gallons per day, plants can realize cost savings of 30% and footprint reductions of 50%" with the larger-size product, Jaferey adds.

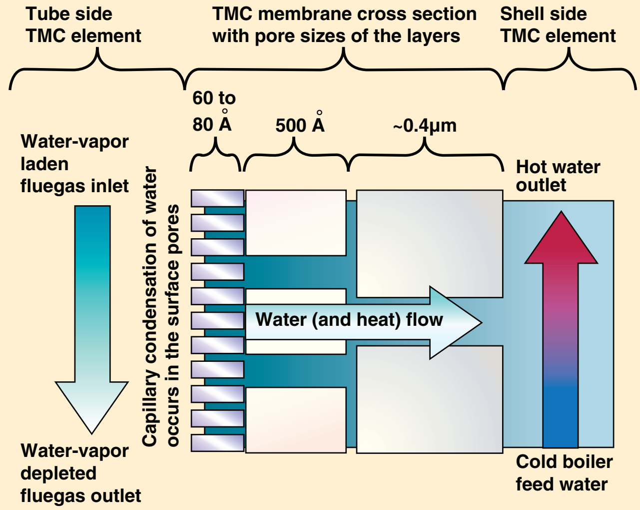
The economics and smaller space requirements become increasingly important as seawater desalination plants seek more capacity and are located in more densely populated areas with limited land space. The product has installation advantages as well because it is available in pre-engineered packaged plants that require less fieldwork to install. As desalination requires pressures of up to 1,200 psi to drive the RO process, KMS also had the challenges of designing larger diameter pressure vessels that could meet ASME code requirements, and delivering them cost-effectively.

Aiding crystal growth

Scientists at Brookhaven National Laboratory (BNL; Upton, N.Y.; www.bnl.gov) have patented a method for absorbing hydrogen fluoride gas to enhance crystal growth. HF is commonly added to precursors to transfer crystalline order from a substrate to a growing material, but buildup of the gas can slow down or even stop the reaction. Simply venting the HF is not practical because other necessary gases may be present, and also pressure variations cause non-uniformity in crystals.

The BNL method features a solid material that selectively absorbs HF, leaving behind oxygen, water vapor and other gases that may be necessary for the reaction. The method has been demonstrated for growing crystals of a common yttrium-barium-copper-oxide (YBCO) superconductor. The YBCO crystal growth rate was faster when using a barium-oxide HF absorber than when conventional methods were used, says BNL. The technology — available for licensing or commercialization — is expected to find applications in superconductors, optical devices and microelectronics.

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



'Super Boiler' achieves higher efficiency through the recovery of waste heat

An advanced heat recovery system (AHRS) that boosts the fuel-to-steam efficiency of firetube boilers by as much as 15% will be produced by Cannon Boiler Works Inc. (New Kensington, Pa.; www.cannonboilerworks.com) through a license agreement with the Gas Technology Institute (GTI, Des Plaines, Ill.; www.gastechnology.org). Cannon expects to have its first commercial units available late this year, for incorporation into new boilers or retrofitting onto existing boilers.

The technology has been proven for high-pressure-steam systems by three field demonstrations at various types of industrial plants over the past three years, says Curt Bermel, GTI's business development manager. The complete system, which GTI calls "Super Boiler," uses a transport membrane condenser (TMC) to capture and use sensible and latent waste heat via the water vapor from fluegas. The Super Boiler consists of a two-pass, high-pressure-steam firetube boiler and an AHRS (diagram), an integrated unit that includes the TMC and low- and high-pressure economizers. Fluegas flows through the economizers, where sensible heat is removed, then passes to the TMC for recovery of sensible and latent heat.

The TMC consists of hundreds of nanoporous ceramic tubes. Cold boiler feedwater flows through the tubes, countercurrent to the fluegas outside the tubes. The flowing water draws the hot, moist fluegas through the membrane to join the flow, thereby recovering heat. About 30–50% of the water in the fluegas passes through the membrane and is recovered as pure water, says Bermel, while the passage of unwanted contaminants, including CO_2 and O_2, is blocked.

A new electrochemical process for making K_2FeO_4

A new process for producing the oxidizing agent potassium ferrate (VI) (K_2FeO_4) can routinely generate multikilogram quantities per day, say scientists. Ferratec (St. Louis, Mo.; www.theincubationfactory.com) and partner Electrosynthesis (Lancaster, N.Y.; www.electrosynthesis.com) have licensed the process technology from Battelle (Columbus, Ohio; www.battelle.org) and are looking toward commercial-scale ferrate production.

The common laboratory method for making the compound involves chlorination of ferric salts, a process that makes only gram quantities and has not been found to be scalable. The new process is based on an electrochemical cell with an iron anode in a strong caustic medium. As low voltage is applied, the cell produces K_2FeO_4 as a slurry, and hydrogen gas. The ferrate is removed continuously from the circulating electrolyte and isolated by solid/liquid separation. Recovered electrolyte is recycled back to the cell.

Relying on electrochemistry rather than chlorination synthesis methods was a key technology development in assembling a viable process and enabling high yields, explain Bruce Monzyk and Mike von Fahnestock, process chemists and engineers at Battelle. The other key innovation, they say, was varying the power across the anode, which eliminates the accumulation of unstable or solid intermediates and keeps the anode from "passivating" — a problem that has plagued past efforts to produce ferrate electrochemically.

Advantages of the new process include a high-purity (>95%), highly stable (tolerates 70°C) product and a small and relatively clean waste stream. The kilogram yields were achieved on a single, commercial-scale cell, but the cells are modular, and can be replicated to scale-up, notes Andy Wolter, chief operating officer of Ferratec and parent company, The Incubation Factory.

Initially, Ferratec is targeting a handful of the many applications for the powerful oxidizer, including use as a broad-spectrum disinfectant, a water quality tool and for selective oxidations in fine chemical syntheses.

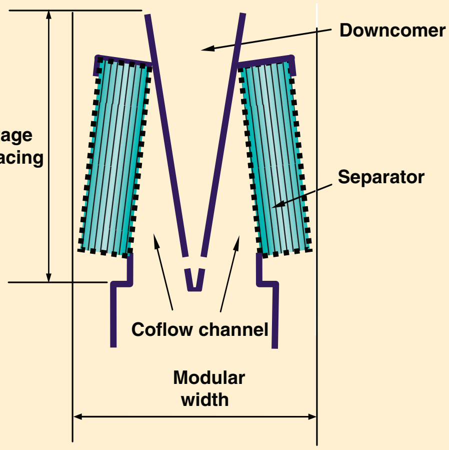
Sound water treatment delivers environmental and economic benefits

A two-year collaboration between Ashland Hercules Water Technologies (AHWT; Wilmington, Del.), a commercial unit of Ashland Inc. (Covington, Ky.; www.ashland.com), and BASF Nederland B.V. (Nijehaske, the Netherlands) has demonstrated that a combination of ultrasonic microbial control and corrosion inhibitors not only enhances environmental performance, but also leads to a dramatic reduction in total operating costs for cooling water treatment. BASF opted to replace its complete cooling-water-treatment program — a conjugated phosphate treatment requiring pH adjustment through sulfuric acid dosing — with Ashland's Enviroplus scale-and-corrosion inhibitor, in conjunction with an Ashland Sonoxide ultrasonic water-treatment system.

Enviroplus uses natural, biodegradeable and renewable ingredients (BCA-polymers and low phosphorous PSA phosphonate), and eliminates the need for sulfuric acid. The patented Sonoxide technology works by passing water through an ultrasonic chamber where

(*Continues on p. 14*)

Commercialization is set for a new distillation technology



A new distillation device developed by UOP LLC (Des Plaines, Ill.; www.uop.com) will make its commercial debut in an ethylene separation column at LG Chem, Ltd.'s petrochemical plant in Yeosu, South Korea. Scheduled for startup in the near future, the revamped column is expected to process twice as much ethylene as it previously did with conventional distillation trays.

The capacity of conventional sieve or fixed valve trays is limited by the froth height and the amount of liquid entrainment that can be achieved, notes Greg Wisniewski, product line manager for UOP process equipment. UOP's technology, called SimulFlow, avoids frothing by entraining all the liquid in the vapor at each column stage. Its high capacity is achieved by simultaneous cocurrent liquid and vapor flow, within a contacting channel, and by efficient vapor-liquid phase separators.

SimulFlow differs from a sieve deck tray in that it has multiple horizontal contacting modules. Each includes a downcomer and two vapor-liquid separators. The latter are located on opposite sides of the downcomer, forming two vapor-liquid coflow channels between the downcomer and the separators (see diagram). Downflowing liquid is distributed through spouts at the bottom of the downcomer and is entrained in upflowing vapor. The two phases are mixed, then split up by the separators. In the case of the LG Chem plant, a mixture of primarily ethylene and ethane is fed to the column. High-purity ethylene is obtained from the top and the ethane is condensed and recovered from the bottom.

SOUND WATER TREATMENT

(*Continued from p. 12*)

bacteria cells are exposed to a combination of low-power, high-frequency ultrasound and micro-bubble aeration. This reduces the overall bacteria levels and eliminates biofilm formation within the entire cooling water system, says Olaf Pohlmann, AHWT's Sonoxide commercial leader EMEA.

After two years of operation, not only was microbial control demonstrated, corrosion rates (measured on steel corrosion coupons) were shown to be reduced from 0.3–0.4 mil/yr to 0.23 mil/yr. Compareing with BASF's previous water treatment costs to those associated with the Sonoxide system, engineers found that operating costs were reduced by 80%, chemical use was reduced by 90% and feed water savings of 20% were achieved. Results also show a preliminary savings of €20,000/yr from feed water and chemical use reductions, says Pohlmann.

DME to propylene

JGC Corp. (Yokohama; www.jgc.co.jp) and Mitsubishi Chemical Corp. (Tokyo, both Japan; www.m-kagaku.co.jp) are investing ¥2.6 billion ($29 million) in a pilot plant to further develop a new process to make propylene from diverse feedstock, such as methanol and dimethyl ether (DME) — made from coke-oven gas — and underutilized olefins from naphtha crackers. The two firms have been working on different aspects of this technology since 2007. JGC, for example, has developed a DME-to-propylene (DTP) process, which uses a modified ZSM-5 zeolite catalyst. The DTP process is said to have a high selectivity for lower olefins, with propylene yields of 70% achieved. The pilot plant, located at Mitsubishi Chemical's Mizushima Plant, is scheduled to come onstream at the end of July.

Biomass-to-liquids

The Karlsruhe Institute of Technology (KIT; Germany; www.kit.edu) has received €11 million in German federal and state funding to extend KIT's pilot plant for developing its bioliq process — a four-stage process for converting biomass (straw or wood) into liquid fuels. The funding will enable KIT to add the last two stages — gas cleaning and fuel synthesis — to its pilot plant. The first stage of the pilot is flash pyrolysis of biomass

(*Continues on p. 16*)

These nanotube membranes promise superior performance for less cost

Carbon nanotube membranes are being developed for water desalination and carbon dioxide sequestration by Porifera Inc. (Hayward, Calif.; www.poriferanano.com) under an exclusive license from Lawrence Livermore National Laboratory (LLNL, Livermore, Calif.). Porifera, a new company, expects to commercialize desalination membranes within two years.

Laboratory tests indicate that the membranes will have "something like 10 to 100 times the flux of polymeric reverse osmosis (RO) membranes, due to a nanofluidic effect unique to carbon nanotubes," says Olgica Bakajin, Porifera's chief technology officer and a former team leader at LLNL. She adds that the membranes will enable an energy reduction of up to 70% in desalination, compared to the use of conventional RO membranes.

The nanotubes are produced by chemical vapor deposition from ethylene or other carbon-bearing gases at 800–850°C, under low or atmospheric pressure. The carbon deposits onto multiple iron-based nanoparticle catalysts, forming an integrated miniature forest of nanotubes. The dimensions of the tubes can be precisely controlled, says Bakajin. The diameters can be controlled within a range of 1–10 nm. The height or length of the tubes, which determines the membrane thickness, is currently 3–5 µm. Working membranes are assembled by embedding the nanotube structure in a porous polymeric or ceramic substrate, with the nanotubes forming the pores of the membrane.

Porifera is also developing membranes that are tailored to separate CO_2 from fluegas. This project, which is at an early stage, is being carried out under a $1 million-plus grant from the U.S. Dept. of Energy's Advanced Research Projects Agency (Washington, D.C.).

(Continued from p. 14)

into a high-energy-density, transportable synthetic crude oil (so-called liqSynCrude). The second stage — gasification of liqSynCrude into syngas — is presently under construction (*CE*, February 2009, p. 12).

A new nuclear fuel

Researchers at Idaho National Laboratory (Idaho Falls; www.inl.gov) have developed a new type of nuclear fuel that leaves less waste compared to conventional fuels. Designed for the Next Generation Nuclear Plant, the new fuel consumes approximately 19% of its low-level uranium, which is more than three times that achieved by commercial light-water-reactor fuel. Each fuel particle contains a kernel of enriched uranium surrounded by carbon and carbide layers that act as containment boundaries for the radioactive material. ❑

A glucaric acid process moves closer to scaleup

An economical method for producing glucaric acid from glucose was successfully scaled up three-fold to a 6-L reactor by its developer, Rivertop Renewables (Missoula, Mont.; www.rivertop.com). The company is planning to assemble a pilot-scale process capable of producing 3-million lb/yr.

Glucaric acid is among a dozen "building-block" chemicals cited by the U.S. Department of Energy (DOE; Washington, D.C.) as having the most significant economic potential as bio-based feedstocks for the chemical industry if they could be produced effectively on an industrial scale.

The Rivertop technology, which can be applied to sugars other than glucose, such as xylose and sucrose, is a highly controlled, nitric-acid-oxidation process carried out in a closed reactor. Computer-based control of the reaction parameters is key to avoiding the thermal issues that are associated with regulating the exothermic reaction. Oxidation of glucose occurs at mild (20–40 °C) temperatures as the oxygen pressure and reaction time are carefully orchestrated. The O_2 that is introduced to the reactor regenerates nitric acid (consumed in the oxidation) by reacting with NOx gases produced in the reaction. Glucaric acid is typically isolated as a water insoluble salt.

Rivertop is targeting the detergent market initially, where glucaric acid could be a nontoxic, biodegradable replacement for phosphates in making household detergents. Glucaric acid could also serve as a corrosion inhibitor and as a concrete admixture.

A commercial debut for microwave-assisted polymerization

A device for the mass production of lactic acid oligomers, polylactic acid (PLA) and other polymers has been developed by Japanese researchers from the Renewable Plastics Group of the Research Institute for Innovation in Sustainable Chemistry, National Institute of Advanced Industrial Science and Technology (AIST; Tokyo; www.aist.go.jp), Glart Inc. (Kanagawa Prefecture; www.glart.co.jp), and Shikoku Instrumentation Co. (KagawaPrefecture; www.yonkei.co.jp), with partial funding from the New Energy and Industrial Technology Development Organization (NEDO; Kawasaki; www.nedo.go.jp). The unit, which utilizes microwaves instead of conventional electrical heaters, reduced the manufacturing time to nearly one tenth that required by conventional methods, requires less energy and generates consistent product with almost no byproducts, says AIST.

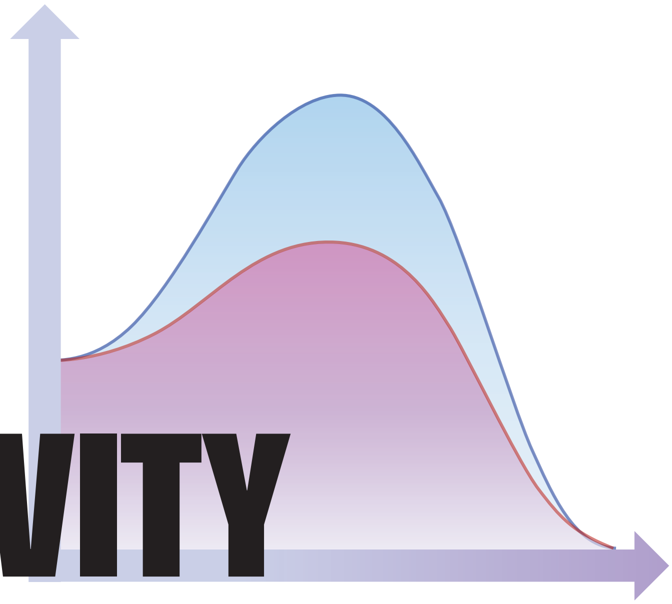
AIST and Shikoku Instrumentation developed a reaction vessel in which microwaves are efficiently absorbed and a technology for handling highly viscous liquids. A 20-L reactor (300-mm dia., 400-mm tall) that can operate at temperatures up to 200°C and pressures to 400 Pa has been constructed and is capable of producing 20 kg per batch. In making PLA, an aqueous solution of lactic acid is simply irradiated by microwaves (6 kW, 2.45 GHz). Unlike conventional routes to PLA, the microwave-assisted reaction requires no tin-based catalyst or sulfuric acid. Glart, which produces oligo lactic acid as functional food materials, introduced this technology into its production line, and says the product is equivalent to, or better than that made by conventional methods.

The patent-pending technology has also been used to demonstrate the solvent-free polycondensation of 1,4-butanediol and succinic acid at 260°C using 0.25 wt.% $Ti(OiPr)_4$ as catalyst, which yields an aliphatic polyester with high strength and molecular weight (1.37×10^5 g/mol). This one-step reaction only takes 75 min compared to the 24 h needed for conventional polycondensation in solution, says AIST.

Demonstration for a wood-to-fuel via DME route

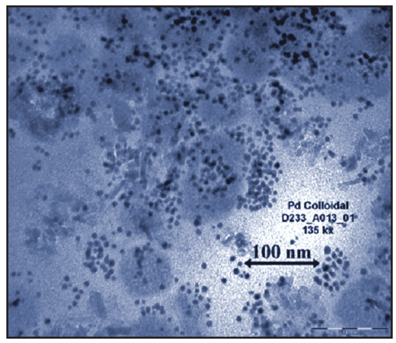
Haldor Topsøe (Lyngby, Denmark; www.topsoe.com) will demonstrate a new technology that converts wood to liquid fuels, as part of a $25-million project funded by the U.S. Dept. of Energy (DOE; Washington, D.C.; www.energy.gov). Among the partners in the project are the pulp-and-paper company UPM-Kymmene, which will supply the wood, and ConocoPhillips, which will show that the new fuel can be used within existing infrastructures. The demonstration plant, which will take place at the Gas Technology Institute (Des Plaines; www.gastechnology.org), will convert 25 ton/d of wood into fuels using Topsøe's integrated gasoline synthesis (Tigas) process. The demonstration will be the final step toward commercializing Tigas.

First developed in the 1980s for converting natural gas into fuel, Tigas converts gasification-based synthesis gas (syngas) into high-octane gasoline through dimethyl ether (DME) as the key intermediate. The demonstration plant will use a multistage gasifier to convert wood into syngas, which is then used to make DME and methanol — the precursors for gasoline. Topsøe says that process integration becomes particularly attractive, because the low H_2-to-CO ratio characteristic of gasification-derived syngas greatly amplifies the thermodynamic enhancement caused by combining the methanol and DME syntheses. The integrated synthesis may therefore be conducted with high efficiency, even at moderate loop pressure, which makes the integrated process suitable for both wet and dry entrained-flow gasifiers, says Topsøe. ■



BOOSTING CATALYST PRODUCTIVITY

Companies are finding different pathways to increase catalysts' ability to produce



BASF

FIGURE 1. Metal clusters with a narrow size distribution, such as these produced on BASF's Nanotechnology platform improve activity while reducing metal content

For the better part of a century, chemical process industries (CPI) have depended on catalysts to make their processes viable. Current efforts toward process efficiency and environmental innocuousness have placed more demands on catalysts to produce more with less.

Industrial catalyst manufacturers are partners in the effort; they are pursuing several different pathways to maximize their products' ability to boost output for those who use them. Among the strategies are to find ways to maintain product yields with less catalyst, and to improve catalyst activity without sacrificing selectivity.

There have been several recent examples where new catalysts have helped realize manufacturing advantages. Success has been reached through the use of alternate catalyst materials, new support designs and new manufacturing methodology.

Engineering particle size

Heterogeneous catalyst activity and selectivity are affected strongly by catalyst particle size. One strategy to improve productivity is to find ways to make uniform-sized catalyst particles that are optimally sized to perform the needed reactions. The BASF (Ludwigshafen, Germany; www.basf.com) catalyst division is applying that approach in its NanoSelect platform, a commercially viable process for manufacturing metal crystallites of a specific size. The first two products under the NanoSelect umbrella are LF100 and LF200, which are the world's first lead-free alternatives to Lindlar catalysts. Lindlar catalysts are lead-modified heterogeneous palladium catalysts that, for example, hydrogenate alkynes to selectively produce *cis*-, rather than *trans*-alkenes.

BASF Catalysts global product technology manager Hans Donkervoort explains that standard heterogeneous catalysts have metal crystallite sizes varying from <1 to 100 nm. The NanoSelect platform is designed to make metal colloids with metal crystallites sized in a very narrow, almost unimodal size range — for example, 7.0±1.5 nm.

"For the LF 100 and 200 catalysts, we are able to produce metal crystallites in a specific narrow range, which allows BASF to achieve the same functionality with the NanoSelect catalyst as that of a Lindlar catalyst," Donkervoort says. In addition, these catalysts require less palladium metal to achieve the same hydrogenation activity, which leads to significant cost reductions in the hydrogenation process. "Palladium content of Lindlar catalysts is about 5% by weight, while the LF 100 and 200 have around 0.5 or 0.6% palladium by weight," Donkervoort explains, "but hydrogenation activity levels are similar."

The BASF LF Series catalysts also eliminate the need for lead. The role of lead in Lindlar-catalyzed reactions is important, but not well understood.

For developing the lead-free hydrogenation catalysts, BASF won a "Green Excellence Award" from Frost & Sullivan (San Antonio, Tex.; www.frost.com) in August 2009.

"Feedback from [LF catalyst] users in the market has been good," Donkervoort says. "Performance is the same [as existing Lindlar catalysts], including selectivity for the *cis* versus *trans* double bond."

The two catalysts constructed on the NanoSelect platform differ in the support material used — in the case of LF 100, the support is activated carbon, and for LF 200, the support is alumina-silicate powder.

BASF's catalyst division is currently working on producing other catalysts on the NanoSelect platform, including multimetallic systems. The company is also seeking collaborations with university research groups to learn more about the fundamental chemistry of the catalyst systems.

In addition to working on new NanoSelect catalysts, BASF engineers are also developing catalysts that are compatible with other strategies manufacturers may be pursuing toward achieving higher productivity in their processes. Succeeding in doing so could include moving from a batch-production model to continuous production, Donkervoort explains. Companies are looking to downsize their equipment and make more product with smaller process hardware, Donkervoort says, and "it's up to us to develop catalysts that will be effective" in such a scheme.

Catalysts for a new reactor

Catalyst particle size figures prominently in another effort where increased productivity is coupled with downsized capital equipment. Oxford Catalysts Ltd. (Oxford, U.K.; www.oxfordcatalysts.com) has developed a method with a goal similar to that of BASF's NanoSelect platform — achieving a narrow, catalyst-particle-size distribution.

One objective of this method, known as organic matrix combustion (OMX), is to help generate catalysts suitable for a process-intensification technology, called microchannel reactors, developed by Oxford subsidiary Velocys (Plain City, Ohio; www.velocys.com).

Microchannel reactors and the catalysts inside were developed, in part, as a way to make the distributed production of biofuels feasible. Biomass density is low compared to petroleum; it takes about one ton of biomass to yield a single barrel of liquid biofuel. To make a biomass-to-liquid-fuels process practical and economically feasible, production facilities need to be small and located near the source of the biomass. A spin-off from the Battelle Memorial Institute (Columbus, Ohio; www.battelle.com), Velocys devised microchannel reactors to enable small biomass-to-liquid production facilities that could be located near biomass sources.

Microchannel reactors are designed to intensify catalytic reactions, such as Fischer-Tropsch (F-T) reactions, allowing for higher productivity with less equipment. Microchannel reactor blocks (Figure 2) are ideally suited to catalytic reactions that are highly exothermic or highly endothermic, and could benefit those for which a conventional reactor architecture limits the reaction equilibrium.

But to take full advantage of the microchannel technology, heterogeneous catalysts need to be extremely active. Oxford's OMX process enables higher activity by manufacturing catalyst particles in a narrow, nanoscale metal-crystallite-size distribution around the optimal size for a particular reaction. The narrow particle-size-distribution curve allows the highest activity while still maintaining sufficient stability, Oxford says. In the OMX method, an organic component forms a complex with the metal salt that effectively stabilizes the metal. The complex undergoes a rapid calcination process that blocks the metal crystallite from growing larger.

The process also generates particles with an ideal surface configuration. OMX produces metal crystallites with "terraced" surfaces to enhance activity, the company explains.

Microchannel reactors contain stacked arrays of parallel reaction channels with sizes in the range of 0.1 to 5.0 mm. Smaller diameter channels dissipate heat more quickly than those in conventional fixed-bed or slurry reactors. By significantly reducing distances required for heat and mass transfer, microchannels help accelerate processes. Oxford Catalysts has been working on new designs for highly active catalysts specifically for F-T chemistry. When coupled with the microchannels, the catalysts help processes realize 50 times higher productivity per gram of catalyst.

For example, in F-T reactions carried out in 1–2-mm microchannels, heat can be removed 20 to 100 times faster than in a conventional reactor. This limits competing reactions, such as those that generate methane. "Microchannels allow you to work under conditions that are more favorable for reaction kinetics," remarks Derek Atkinson, business development director for Oxford Catalysts.

Temperature differences across microchannel reactors are small — typically 1ºC, compared to a 20 to 40ºC differential often observed in conventional reactors. Also, conversion rates for carbon monoxide of greater than 70% per pass have been observed, compared to 45–60% in fixed bed or slurry bed reactors.

Oxford and Velocys are building an installation to demonstrate the microchannel technology at a biomass gasification plant in Gussing, Austria. The facility will use gasified woodchips as a feedstock for F-T chemistry and will have a capacity of about 10,000 gal/yr.

The plant is expected to be operational in early 2010 for the beginning of a six-month demonstration period, after which the reactor skid will be moved to Wright-Patterson Air Force Base near Dayton, Ohio to test its applicability to producing synthetic jet fuel. Goals of the demonstration plant are to learn about process upsets and catalyst poisoning.

Optimizing performance

Efforts aimed at squeezing more productivity from processes using heterogeneous catalysts can focus on other areas, including tweaking catalyst crystal structure, reducing energy requirements and refining catalyst selectivity.

Süd-Chemie AG (Munich, Germany; www.sud-chemie.com) found a way to improve productivity in traditional ammonia synthesis by stabilizing a new catalyst crystal structure. The new catalyst contains less oxygen in its crystal structure than its predecessors, and therefore shortens the reduction time. It also exhibits up to 40% higher activity. Combined, the advantages in the new ammonia synthesis catalyst improve energy efficiency significantly for ammonia producers and could boost ammonia production by up to 5%.

"A 5% increase in ammonia production can translate into millions of dollars annually in a typical-sized plant," remarks Yvonne Zhang, vice president for global marketing in the catalyst technology unit of Süd-Chemie. The better-performing crystal structure was discovered by a China-based academic research group and was licensed by Süd-Chemie from Zhejiang University of Technology.

Oxford Catalysts / Velocys

FIGURE 2. Velocys microchannel reactors have improved heat transfer properties and require highly active catalysts

Improving the selectivity of catalysts that are marketed is being pursued by a number of companies in the catalyst business, including CRI Catalyst, a subsidiary of Royal Dutch Shell Group (London, U.K.; www.shell.com) and Grace-Davison (Columbia, Md.; www.gracedavison.com). In many cases, improved selectivity means higher productivity, in the form of higher yields of desired products versus side products.

CRI Catalyst plans to introduce a product early this year that will improve selectivity in styrene production. The catalyst is designed to maintain the activity of its predecessors while boosting selectivity, says Laurent Fenouil, global business director for CRI/Criterion's styrene catalyst unit. Fenouil says the driving force for the company's catalyst business is increasing catalyst activity and selectivity, along with lengthening product lifetimes to help its customers optimize efficiency. In the future, the styrene sector will see a "renewed emphasis" on energy cost and energy usage, Fenouil notes, adding that CRI will be working on catalysts that help users reduce energy use while retaining the same performance characteristics.

In many areas, productivity becomes an economic imperative based on feedstock costs. For example, producers of polyolefins are searching for catalysts that will allow them to improve both production and economics. Grace-Davison global marketing director for polyolefins Jewan Bae says his company is working to develop catalysts to do just that. The demand can especially be felt among resin producers in Europe, Japan and Korea, who must produce more to compete with companies in China and the Middle East, where feedstock costs are lower. Bae says for now, North American companies can compete on costs with Chinese and Middle Eastern firms, because the cost of natural gas is relatively cheap, but in a few years that won't be the case.

Bae and Grace are looking for the increased costs to push many companies toward producing specialty products instead of commodity polyolefins. Producers are already going in that direction, Bae says, because they can command premium pricing. Grace is looking to help in that effort also, by working with industry partners to develop and commercialize stereoselective catalysts based on metallocene chemistry, Bae explains. Metallocenes consist of a metal atom bound to, and sandwiched by, two cyclopentadiene rings.

Metallocenes are an example of metal-organic complexes, which may become increasingly common as industrial catalysts in the future as chemists and engineers learn the details of their function and work out viable production processes.

University catalyst research

Projected demand among CPI companies for catalysts that exhibit higher activities, enhanced selectivity, reduced environmental impact, or posess other desired performance parameters have many companies looking not only to recently developed technologies, but also to academia for new developments that could spur the next generation of industrial catalysts. A significant portion of industrially relevant catalyst work in academia is focused on engineering metal-organic complexes to serve as catalysts and supports. An example is work led by Ferdi Schüth at the Max Planck Institut für Kohlenforschung (Mülheim an der Ruhr, Germany; www.kofo.mpg.de). Researchers there, along with collaborators elsewhere, have developed a new catalyst for oxidizing methane into methanol. The new catalyst mimics a previously studied homogeneous catalyst based on platinum and bipyrimidine, but has the additional and important property of being a solid material that can act as a heterogeneous catalyst with much less energy required to separate it by filtration. The catalyst is characterized by a highly porous covalent triazine-based network into which platinum metal powder is added so that the Pt atoms reside within the lattice of the organic framework. The methane is oxidized into methanol in heated sulfuric acid. Schüth and colleagues are now trying to enable the process to work with reactants in the gaseous state. The work could eventually be used to make it cost-effective to monetize previously unused natural gas resources.

A research team at the University of California at San Diego (www.ucsd.edu) has demonstrated catalytic activity after post-synthetic modifications of metal-organic frameworks (MOFs). In synthesizing the hollow-latticed MOFs, the researchers substituted an amine-containing molecule for a similar molecule that served as a linker for the MOF structure. Including the amine group allowed the team to functionalize the MOF with other molecules that give rise to catalytic activity. They "bolted on" two cyclic anhydrides capable of chelating an iron atom, which can be used as a catalytic active site. The research could eventually give rise to a new type of tunable catalyst for specific synthetic tasks.

Meanwhile, Korean scientists have succeeded in making ultrathin zeolite sheets that may have advantages as efficient catalysts for hydrocarbon cracking and other petrochemical applications. The thinness of the zeolite sheets allows reactants to rapidly and easily diffuse into the zeolite structure while products diffuse out. Working at the Korean Advanced Institute of Science and Technology (Daejon, South Korea; www.kaist.edu), researchers directed the growth of a thin zeolite sheet with surfactant molecules that acted as templates. The polar end of the surfactant consists of two quaternary ammonium groups around which the zeolite crystal grows. The non-polar tails prevent the growing zeolite crystals from aggregating together into larger, three-dimensional crystals. The surfactant template is removed, leaving thin zeolite flakes, which pile up randomly with gaps to aid diffusion to the catalytic sites. ■

Scott Jenkins

RECOGNIZING YOUR COLLEAGUES

Consider nominating a deserving colleague for our 2010 Personal Achievement Award. Entries are due April 15

In professional life, the influences that teach us, inspire us and drive us to succeed tend to come more from individuals than corporations. If you would like to bring recognition to someone whose excellence in chemical engineering you admire, consider nominating him or her for *Chemical Engineering's* 2010 Personal Achievement Award. The nomination period is now open.

The aim of this award, which *Chemical Engineering* (*CE*) has offered biennially since 1968, is to honor individuals for distinguished careers. It complements *CE*'s Kirkpatrick Award for Chemical Engineering Achievement, presented in the alternate years, which honors companies — as opposed to individuals — for specific chemical-process accomplishments (see December, p. 17).

Our Personal Achievement Awards have saluted excellence in diverse areas — research, development, design, plant operations, management and other activities. The distinction can emerge in less-ordinary ways, such as government service. The criterion is that the career must have related, fully or largely, to the use of chemical engineering principles in solving industrial, community or other problems.

It's easy to nominate

Submitting an award nomination is a simple matter:

1. State the name, job title, employer and address of the candidate.
2. Prepare a summary, in up to about 500 words, that highlights your nominee's career and brings out his or her creativity and general excellence in the practice of chemical engineering technology. At least some of the activity must have taken place during the three-year period ending Dec. 31, 2009. Be specific about key contributions or achievements. But do not include confidential information in your writeup.
3. Please be sure to include your own name and address, in case we need to contact you.
4. Send your nomination no later than April 15 to:

Nanette Santiago
Chemical Engineering
110 William St., 11th floor
New York, NY 10038
Email: awards@che.com

We encourage you to ask others to provide information in support of the nominee; ask them to write to us by April 15. Such input has often proved to be decisive during the judging.

What's next

Once we receive a nomination, we will ask the candidate whether he or she is willing to be considered (you may instead do so yourself and include a note to that effect in your nomination). Meanwhile, we might take any steps that seem called for to verify the accomplishments stated in the brief or the supporting letters.

Next, we will send all the nominations to a panel of senior chemical engineering educators, who will evaluate and rank them. Based on the voting of these judges, we will designate one or more winners. Then we will inform all the nominees and nominators about the results of the voting.

An article in *Chemical Engineering* around the end of this year will profile the winners. Around the same time, we will present physical embodiments of the awards to these individuals.

Points to keep in mind

Nominees can be from any country. They need not hold a degree in chemical engineering. But their achievements must have involved use of chemical-engineering principles in solving problems, and part of the activity must have been in 2007 – 2009.

The Personal Achievement Award has been hailed and respected since its inception. We welcome your nomination, to help us maintain this worthwhile activity. ■

Rebekkah Marshall

RECENT AWARD WINNERS

When thinking about whom to nominate, keep in mind that a distinguished career can take many forms. Here, for instance, are the most recent winners:

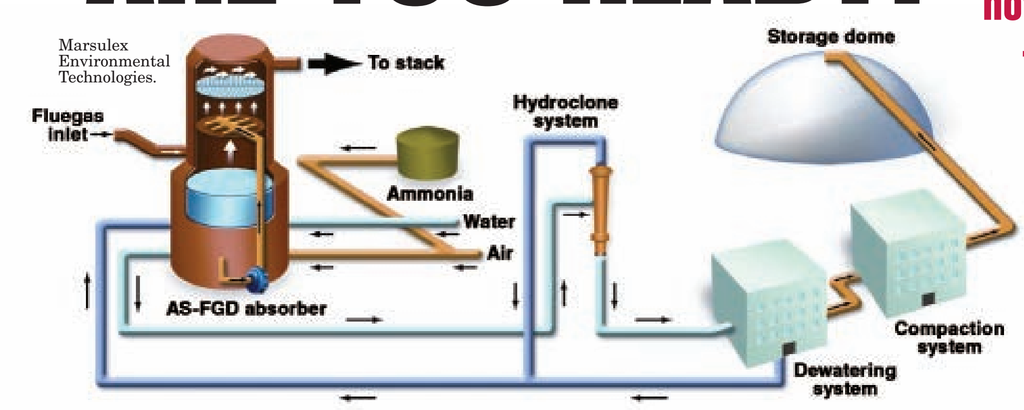
Brian W. S. Kolthammer, research fellow at The Dow Chemical Co., may be best known for his pioneering work in the kinetic modeling of catalyst systems and their process adaptation to solution, process-polymerization plants for the manufacture of polyolefins. This work has enabled record pacing in the successful scaleup and commercialization of new, major plastomer and elastomer product lines.

Shyam Lakshmanan, group general manager at See Sen Chemical Bhd & Malay-Sino Chemical Industries Sdn Bhd, has been hailed as the "foremost person" at his company responsible for achieving plant capacity improvements and water, fuel and electricity savings.

Henry Kister, of Fluor, has been hailed as the world's foremost authority on distillation and absorption troubleshooting. He has written two widely consulted engineering books on distillation, as well as over 70 articles, and has taught courses and spearheaded symposia in distillation. ❏

ARE YOU READY?

With stricter air-pollution-control regulations on the horizon, now is the time to examine the newest scrubbing technologies



Ammonium sulfate technology, which serves as an alternative to traditional wet fluegas desulfurization, uses aqueous or anhydrous ammonia to convert SO_2 emissions into a high-quality, high-value commercial grade ammonium sulfate crop fertilizer

Most members of the highly regulated chemical process industries (CPI) are aware of the growing worldwide attention focused on the issues of climate change, air and water pollution and the supply and protection of natural resources. For this reason, air-pollution-control scrubbers play an integral role in most chemical processing facilities. However, the economic downturn caused many processors to shelve air-pollution-control projects during the past year. But with the recent hint of potential regulatory action in the air, it might be wise to dust off those project plans and take a look at the newest scrubbing technologies designed to help processors meet current and future air-pollution-control challenges and "green up" their scrubbing processes at the same time.

Next in the regulatory pipeline

While there is currently uncertainty in the area of upcoming CO_2 legislation, experts in the industry suggest that there will be some new mandates regarding carbon capture technology in the future. "For this reason we see many processors interested in driving down emissions for CO_2, as well as SO_2, SO_3 and NOx to significantly lower levels than where they currently operate," says Tony Licata, vice president of Babcock Power Environmental (Worchester, Mass.; www.babcockpower.com).

In addition to CO_2 legislation, a new proposed air-pollution rule that would significantly alter permissible air-pollution-control levels in the U.S. would require the installation of scrubbers on more than 200 cement kilns, according to Bob McIlvaine, president of the McIlvaine Co. (Northfield, Ill.; www.mcilvainecompany.com). "There would be new Maximum Achievable Control Technology (MACT) rules, which would result in scrubbers being placed in most cement plants," he says.

Similarly, he says, MACT regulations regarding hydrochloric acid in power plants may result in the installation of new scrubbing technologies in these facilities. "It would be a 'make lemons into lemonade' situation because rather than removing the HCl and having it as a contaminant in wastewater that would require further treatment, we believe a two-stage scrubbing system that captures HCl in the first stage and SO_2 in the second, allowing processors to make both hydrochloric acid and gypsum, is likely to become the technology of choice."

McIlvaine says that while such a system would involve billions of dollars in investment, the technology already exists and is employed in Europe, which proves it is a viable solution to potential legislation in the U.S.

Other possible regulatory action to consider includes a revisit of the Boiler MACT by the U.S. Environmental Protection Agency (EPA; Washington, D.C.), says Kevin Moss, business development director, with Tri-Mer (Owosso, Mich.; www.tri-mer.com). He notes that while Boiler MACT was developed a few years ago, it was shelved because it was not being applied uniformly. "There's been another round of EPA going back to formulate a new Boiler MACT. The regulation was released in April for comment and will likely be law by December 2010," says Moss. The rule would give companies with boilers burning coal, wood or solid fuels three years to comply with the new MACT regulations.

And, aside from the possibility of new mandates concerning air pollution control, many industry experts get a sense of stricter enforcement on existing regulations. "What we are starting to see is a much more active EPA under this administration," says Moss. "There's more aggressive enforcement of laws already on the books, so now is a good time to start taking a serious look at air pollution control."

New technologies deliver

For this reason, many scrubber manufacturers are bumping up their game and striving to improve existing technologies or develop new ones in an effort to meet or exceed today's mandates, as well as any that are expected to come down the pike.

For example, to help with compliance of stricter Boiler MACT regulations, Tri-Mer is offering the UltraTemp Filtration (UTF) system. "We expect as they regulate particulate matter coming from boilers, they are likely to further regulate SO_2, HCl and other acid gases," says Moss.

UTF technology uses ceramic tube filters made of ductile ceramic fibers, which are able to handle the high temperatures (applications up to 1,000°F and temperature resistant up to

1,650°F) of boiler exhaust gases and filter the particulate down to very low levels. The system offers a very high efficiency and can handle even submicron particulate matter. The UTF system can also be employed for concurrent gas scrubbing, to remove acid gases through injection of a dry scrubbing agent, such as limestone or Na_2HCO_3.

Also intended to meet stricter regulations regarding acid gases is Babcock Power Environmental's Turbosorp Dry Circulating fluid-bed scrubber for processes requiring dry technology. The system removes acid fluegas constituents, primarily SO_2 and SO_3, as well as mercury, HCl and HF from coal-fired boilers. Turbosorp is available for capacities up to 300 MW per turboreactor and is suited for facilities with sulfur contents below 3%. Acid gas removal efficiencies of 95 to 97% are typical.

The principal of the scrubbing technology is to bring high levels of solid recirculation, finely atomized water, hydrated lime and fluegas within a circular fluid-bed reactor. Lime and finely atomized water are injected independently into the turboreactor to lower fluegas temperature and enhance absorption capacity.

The fluid bed material is comprised of solids, including $Ca(OH)_2$, fly ash from the combustion process and solid reaction products from the fluegas particulate-matter device. Upon leaving the turboreactor, the solids are separated from the fluegas in either a fabric filter baghouse or an electrostatic precipitator and recycled back to the reactor. Where mercury and dioxin removal are required, activated carbon can be injected into the turboreactor.

Envirofriendly systems

While the goal of all air pollution scrubbers is to save the environment from toxic gases and particulate matter (while helping the processor meet regulatory mandates), many scrubber manufacturers are working to make the scrubbing systems themselves as safe for the environment as is possible, while still producing results that meet or exceed current and expected regulations.

Bioscrubbers, one of the most common types of environmentally friendly scrubbing systems available, have been around for over 20 years, but have previously found only limited use in VOC (volatile organic compound) removal applications. "Bioscrubbers were thought to be a low-tech approach," says Moss. "They simply weren't able to get to high efficiencies and had a limited number of VOCs they could attack."

However, recent technology upgrades have made this type of system more viable than ever before. For instance, Tri-Mer's MultiPhase Bioscrubber overcomes the disadvantages of conventional bioscrubbers designed for the biological treatment of air pollutants by treating incoming contaminants in the phase (liquid or gas) in which the contaminant would normally reside, depending on its inherent properties.

For example, a highly volatile compound with low water solubility will concentrate in the bioscrubber gas phase, and will be treated mainly in the gas phase. Highly water-soluble compounds with low volatility will concentrate in the bioscrubber water phase and will be treated in the water phase. Most compounds with intermediate volatility and water solubility will be treated in both the gas and water phases, depending on their natural partitioning.

Conventional biofiltration systems attempt to treat all the contaminants in the gas phase, whereas a conventional bioscrubber delegates the treatment of the water-soluble fractions of the contaminants to an external treatment system, often with design flaws that can either partially re-entrain the contaminants into the ambient environment or allow the contaminants to accumulate and escape through the water.

None of the conventional systems are designed to handle particulate matter in the gas phase, treat condensables with high molecular weight, nor handle the dissipation of heat if the incoming stream is above the normal operating temperature of aerobic organisms (50 to 105°F).

However, the newer MutliPhase Bioscrubber system can handle much higher inlet temperatures from dryers. Often, exhausts from press vents and dryers are treated together, producing significant cost advantages.

Other advantages of the MultiPhase Bioscrubber technology include the ability to accommodate high particulate loads, compatibility with high inlet concentrations of VOCs, high efficiency removal, permanent ceramic media, automatic self cleaning and the ability to handle tars, waxes and heavy VOC compounds. Also, waste generation is minimal with no NOx compound creation.

Similarly, Duall Division of Met-Pro (Owosso, Mich.; www.dualldiv.com) has recently launched its line of Bio-Pro Scrubbers. These scrubbers are touted as being 100% environmentally friendly and are efficient at controlling and removing H_2S emissions and odors. "The real drive toward improving and embracing bioscrubbers is the fact that you are using green technology versus chemicals," says Greg Kimmer, vice president and general manager of Duall. "Not only is it a natural technology, but in this economic climate, it is efficient because you aren't spending as much on chemicals."

Duall's Bio-Pro employs a state-of-the-art biotrickling filter technology in combination with a unique blend of micro-organisms to provide 99% H_2S removal with a side range of inlet loadings and provides an environmentally safe byproduct.

Another environmentally friendly option comes from Purafil Environmental Systems (Doraville, Ga.; www.purafil.com). The Purafil ESD FOC-1, fiberglass Emergency Gas Scrubber (EGS) with Chlorosorb dry scrubbing medium uses a non-toxic, dry-scrubbing medium in place of a toxic, liquid caustic to neutralize gases in the event of an emergency situation. This medium's "chemisorptive" process removes chlorine by means of adsorption and chemical reaction. Chlorine gas is trapped within the pellet where an irreversible chemical reaction changes the gases into harmless solids.

This type of emergency standby equipment is necessary for facilities that store large quantities of Cl_2, typically in one or more one-ton cylinders to prevent accidental chemical releases. If a toxic gas release from a one-ton cylinder were to occur, the thermodynamic properties of Cl_2 suggest that approximately 400 lb of liquid Cl_2 would flash into vapor and the remaining contents of the cylinder would spill out as a liquid at its boiling point. According to the American Water Works Association's Risk Management Program, the outer limit of the impact area, in a Cl_2 release, is drawn at a five-mile radius in all directions from the point of impact.

Purafil's dry chemical EGS is designed to contain the entire contents of a fully loaded one-ton Cl_2 cylinder in a worst-case scenario. The EGS can neutralize an initial 400 lb in the first minute and any additional chlorine at a rate of 80 lb/min thereafter.

Ammonia scrubbing is also seeing a rise when compared to calcium-based technologies, since ammonia is carbon neutral. "Ammonia scrubbing doesn't contribute incremental CO_2 to the atmosphere," notes Dave Olson, vice president of licensing and commercial operations with Marsulex Environmental Technologies (Lebanon, Pa.; www.marsulex.com). And, Marsulex Environmental's new ammonia scrubber takes it even further. "It can be used to make and sell commercial grade fertilizer for more than it costs for the ammonia to make that fertilizer, so you can generate some revenue back to pay for other operating costs of the plant," notes Olson.

In addition, the fertilizer made from Marsulex's ammonium sulfate (AS) fluegas desulfurization (FGD) technology can be used to grow more plants and crops, especially those that are high in photosynthesis. "The so-called 'C4 plants' that are high in photosynthesis help with CO_2 absorption from the atmosphere," explains Olson. "So it's a very efficient technology and very effective for the kind of environment we are looking at today."

AS Technology, which serves as an alternative to traditional wet FGD, uses aqueous or anhydrous ammonia to convert SO_2 emissions into a high-quality, high-value, commercial-grade ammonium-sulfate fertilizer. Most beneficial in power, petrochemical and industrial plants with higher sulfur fuels, proximity of navigable water or good rail access and locations with regional demand for high-quality crop fertilizer, the technology provides longterm environmental compliance and requires no chemical or byproduct waste handling. Every ton of NH_3 used generates approximately four tons of ammonium sulfate fertilizer.

Other benefits include water-soluble chemistry that prevents internal build up, NH_3 reagent with 98% removal efficiency with unlimited sulfur contents and the elimination of liability associated with waste product disposal.

While no one knows exactly what tomorrow's regulatory environment will bring, the technologies to meet the likely mandates currently exist, making now the time to see what options are available and get the right one for your facility in place. ■

Joy LePree

CHEMICAL ENGINEERING
FACTS AT YOUR FINGERTIPS
Department Editor: Scott Jenkins

Low-Pressure Measurement

Because of the behavior of materials under vacuum, including lowered boiling points, low-pressure operations are useful tools in chemical processing, as well as in research and development and manufacturing. Areas where a vacuum system is necessary or useful include the following:

- Separating liquids
- Processing temperature-sensitive materials
- Preventing unwanted chemical reactions between process materials and the surrounding environment by removing air
- Improving heat transfer through liquids by removing air
- Drying solutes (removing solvent)
- Initiating materials transfer or aiding filter processes by applying differential pressures
- Depositing thin-films on surfaces, such as in the microelectronics industry and other areas
- Testing with mass spectroscopy

LOW-PRESSURE MEASUREMENT

Because of vacuums' central role in processing and research, it is important to be able to measure pressures that may be a tiny fraction of typical atmospheric pressures.

Table 1 shows a typical breakdown of vacuum quality. The ranges do not have universally agreed-upon definitions, however.

TABLE 1. TYPICAL RANGES FOR VACUUM QUALITY

	Pressure in torr	Pressure in Pa
Atmospheric pressure	760	101.3 kPa
Low vacuum	760 to 25	100 to 3 kPa
Medium vacuum	25 to 1×10^{-3}	3 kPa to 100 mPa
High vacuum	1×10^{-3} to 1×10^{-9}	100 mPa to 100 nPa
Ultrahigh vacuum	1×10^{-9} to 1×10^{-12}	100 nPa to 100 pPa
Extremely high vacuum	<1×10^{-12}	<100 pPa
Outer space	1×10^{-6} to 3×10^{-17}	100 µPa to < 3fPa (1fPa = 10^{-15} Pa)
Perfect vacuum	0	0

At pressures below 1 torr, forces exerted by gaseous molecules are not sufficient to measure directly with an absolute pressure gage. Pressure must be inferred by assessing a pressure-dependent physical property of the gas, such as thermal conductivity, ionizability or viscosity.

IONIZATION GAGES

Ionization gages (IGs) are one class of instruments for indirect measurement of gas density and pressure. IGs generally work by ionizing neutral gas molecules, then determining their number by measuring an electrical current. Characteristics of ionization gages include and electron source, an ion collector that is negative relative to the cathode, an acceleration voltage of about 100V, and a mechanism for measuring electric current.

Emitting-cathode ionization gages

One type of IG can be classified as emitting-cathode IGs (ECG) (also known as hot-cathode IGs). These are characterized by a heated filament that serves as source of electrons.

An example of an emitting cathode ionization gage is a Bayard-Alpert (B-A)-type ionization gage. In a B-A-type gage, electrons are emitted in a well-controlled, regular fashion from a heated filament (cathode) and accelerated toward a positively charged wire grid anode.

As electrons pass through the space between the electrodes, they collide with gas molecules in the vacuum system to generate positive ions. At a constant filament-to-grid voltage and electron emission rate, the formation of positive ions is directly proportional to the density of the molecules (pressure) in the gage.

The useful operating range of a conventional B-A-type gage extends between 10^{-3} and 10^{-10} torr.

Crossed-electromagnetic-field IG

Another broad type of ionization gages can be classified as crossed-electromagnetic-field (EMF) IGs (also called cold-cathode IGs). This IG type is characterized by the generation of a discharge between cathode and anode that is maintained with a magnetic field.

An example of this IG type is a Penning gage. A Penning gage maintains a cathode-anode discharge by applying a magnetic field. The magnetic field prevents the electrons from traveling directly to the anode; instead, they travel in helical paths through the vacuum space.

The electrons can ionize gas molecules in the vacuum when they have sufficient energy. Since the resulting gas ions have much greater mass than electrons, they are unaffected by the magnetic field and are captured.

The probability of collisions is proportional to gas density. The current generated by the ion collection process is an indirect indication of vacuum pressure.

Table 2 compares the advantages and disadvantages of emitting-cathode IGs and crossed-EMF IGs.

TABLE 2. ADVANTAGES AND DISADVANTAGES OF ECG VERSUS CROSSED-EMF IONIZATION GAGES

	Advantages	Disadvantages
Emitting-cathode IGs	• Accuracy better than crossed EMF, especially at very low pressures • More easily calibrated than crossed EMF • Less affected by external magnetic fields • Electron emission current can be controlled, stabilized and varied	• Longer delays to acquire a stable reading • Do not handle chemically active gases well (other than N_2, H_2 or rare gases)
Crossed electromagnetic field IGs	• Can be turned on at higher pressures during a pumpdown • No X-ray limit (electrons produce X-rays, which generate photocurrent that is indistiguishable from measured current) • Electron-stimulated desorption effects are small	• Output varies non-linearly with pressure • Pumping speed higher than emitting cathode gages and cannot be controlled • Electron space charge trapped in the gages leads to instabilities

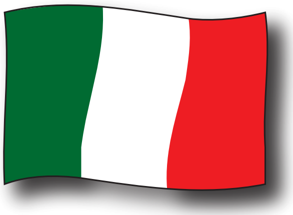
Selecting IGs

A number of factors should be considered when selecting IGs for pressure measurement in the high- and ultrahigh-vacuum ranges. These considerations include the following:

- Pressure range required for application
- Gage pumping speed
- Identity of gas species to be measured
- Accuracy and stability
- Size and mechanical stability
- Interferences with magnetic fields
- Price

References

1. Jousten, K. "Handbook of Vacuum Technology," John Wiley and Sons Inc., Hoboken, N.J., 2008.
2. Pacey, D.J. Measurement of Vacuum. In: "Instrumentation Reference Book, 3rd edition (ed. by Walter Boyes), Butterworth-Heinemann, Burlington, Mass. 2002.
3. Vibert, P., Mechanical Pumps for Vacuum Processing – Part One. *Chem. Eng.*, Oct. 2004, pp. 44–51.
4. Stanford Research Systems Inc., Hot vs. Cold Ionization Gauges. Technical application note, 2007. www.thinksrs.com
5. Brooks Automation Inc. Introduction to Bayard-Alpert Ionization Gauges. Technical note 706, 2007. www.brooks.com



Italy 2010

Special Advertising Section

"Timid" recovery for Italian chemicals during 2010

The economic crisis has hit Italian chemical companies badly. Industry association Federchimica expects around 4% growth this year, but fears long-term structural damage

Italian chemical manufacturers have been suffering the effects of the global recession to much the same extent as their competitors in other European countries.

According to **CEFIC**, the European chemical industry council (Brussels; www.cefic.be), by October 2009 chemicals production in Italy (excluding pharmaceuticals) had fallen by 17.8% compared to the peak of January 2008. Output for the first eight months of the year was 16.9% below that for the corresponding period in 2008.

This is comparable with what has happened in Germany (–21%), Belgium (–17.8%), Italy (–17.8%), and the UK (–15.5%), with France (–13.6%) and Spain (–5.5%) escaping somewhat more lightly. As a result, said CEFIC, overall EU chemicals production in August 2009 was 17% lower than in January 2008.

The situation has improved slowly following the sharp drop in EU chemicals production at the end of 2008. By August 2009, production was 12.4% higher than that the trough of December 2008. But there is still a considerable way to go, CEFIC warned.

Average chemical prices (excluding pharmaceuticals) were 3.8% down in the first eight months of 2009 compared to the corresponding

Continued on p. 24I-2

Italian innovation

Downstream restructuring may cut the number of customers for the chemical industry

©LEON1 | DREAMSTIME.COM

Continued from p. 24I-1

period in 2008, and prices in August 2009 were 7% lower than those of a year before. From January to August 2009, European chemicals sales were 23.2% down on the same period of 2008.

With this background, Italian chemical industry association Federchimica (Milan; www.federchimica.it) was by July 2009 forecasting a "timid" Italian recovery for 2010.

Lower mortgage interest rates, low inflation and a fall in energy prices mean that household consumption in Italy will not collapse unless the recession is sufficiently prolonged as to create a big increase in unemployment, Federchimica said.

But the situation is different for manufacturing industry, especially durable and investment goods, and sectors connected with construction. European industrial production is expected to have fallen by 16% in 2009, followed by modest growth of +4% in 2010.

Permanent effects

The scale of the crisis is producing widespread restructuring, Federchimica pointed out. The implication is that the European and Italian chemical companies are facing not only a squeeze in demand, but also a fall in the number of their customers and, in some downstream sectors, permanent downsizing.

Many Italian manufacturing companies were caught by the crisis in the course of a transformation to improve quality, increase innovation and become more international in outlook. Especially hard hit will be SMEs and financially exposed companies, such as those whose profitability was already declining before the crisis, such as household appliances, paper, automotive, building materials, textiles, rubber and plastics. ■

An international partner with an Italian heart

To pumpmaker Pompetravaini, innovative products and global sales are both vital

Pompetravaini has been marketing centrifugal and vacuum pumps to the chemical industry for 80 years, so is a well-known name worldwide.

More than 30 years ago the company started to serve international markets by opening sales and manufacturing branches in the US and Canada. During the 1980s and 1990s the company set up branches in Germany, the UK and the Netherlands, the latter also covering Belgium and Luxembourg. At the beginning of the new millennium Pompes Travaini France completed the coverage of central-western European markets, as well as former French colonies. Travaini's newest offspring, born two years ago, is Travaini Pompy Polska, which looks after the Polish market and other countries in eastern Europe, including the Baltic republics.

PompeTravaini's Hydrotwin 6 with its Roots blower and TRVX 1007 liquid-ring vacuum pump features sophisticated electronic control

At the same time, the parent company Pompetravaini has been developing a global network of distributors to guarantee the local availability of pumps, spares and technical expertise from South Africa to Iceland and from Australia to Chile. Over the last three years the Pompetravaini Group has shipped pumps and vacuum packages in over 81 different countries and issued technical documentation in 10 different languages. Even now, Pompetravaini is continuing to make plans for new outlets in new territories.

This international presence, though a priority for Pompetravaini, is not sufficient in itself, so the group continues to develop innovative products every year. At the Achema exhibition in Frankfurt in May 2009 Pompetravaini launched three new liquid-ring vacuum pumps in its patented TRVX series, which features enhanced performance, compact dimensions, lower weight, improved mechanical strength and attractive design.

Achema was also a runway success in new vacuum packages, the company says. Oilpack is a compact vacuum package which uses oil as the seal liquid to achieve vacuum of 15–20 mbar(a) with zero water consumption. The other great novelty in Pompetravaini vacuum packages is the Hydrotwin, a combination of a Roots blower and a liquid-ring vacuum pump sealed with water or oil. Electronic control systems provide increased energy efficiency at high vacuums (down to 2 mbar(a)) and avoid any risk of dangerous overheating.

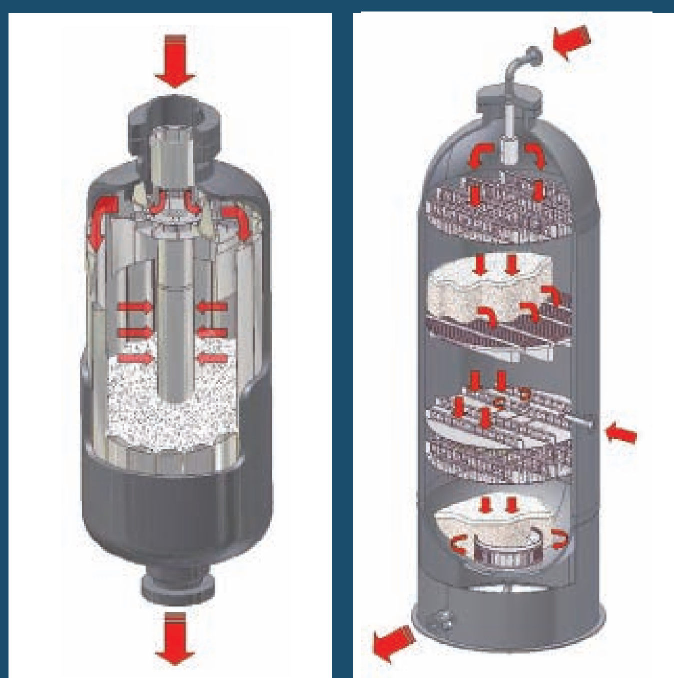
www.pompetravaini.com

For more than eighty years, we at **Costacurta** have been constantly and resolutely committed to the development and manufacture of special steel wire and plate components used in many different industrial processes. Every day at **Costacurta**, we work to improve the quality of our products and services and the safety of all our collaborators, paying ever-greater attention to the protection of the environment.

Within the wide range of **Costacurta** products you will also find some, described below, that are used specifically in the *oil, petrochemical and chemical industries:*

- *RADIAL FLOW AND DOWN FLOW REACTOR INTERNALS;*
- *GAS-LIQUID AND LIQUID-LIQUID SEPARATORS;*
- *ARMOURING OF REFRACTORY, ANTI-ABRASIVE AND ANTI-CORROSIVE LININGS.*

For more information visit our website or contact the **division 'C' components for the oil, petrochemical and chemical industries** at **tcrc@costacurta.it**.



Radial Flow and Down Flow reactor internals

VICO Costacurta

www.costacurta.it

Costacurta S.p.A.-VICO
via Grazioli, 30
20161 Milano, Italy
tel. +39 02.66.20.20.66
fax: +39 02.66.20.20.99

Management systems
certified by LRQA:
ISO 9001:2008
ISO 14001:2004
OHSAS 18001:2007

Circle 20 on p. 62 or go to adlinks.che.com/29246-20

Conical dryers ensure an improvement in drying

Comber is a leading manufacturer of batch equipment for hygienic applications, with a special focus on dryers of both vertical and horizontal types

Comber, which specializes in filtration and drying equipment, has recently improved the design of the agitator in its Condry conical-bottom vertical pan dryer. The agitator now takes the form of two half spirals. This has considerably reduced the drying time, the company says, while the conical bottom ensures easy discharge and cuts the amount of residual product left inside the vessel to below 1%.

Comber's Condry: now even more effective thanks to spiral agitator arms

By avoid excessive friction, the new agitator avoids damaging delicate products, while at the same time providing excellent mixing at low speeds. Simultaneous rotational and vertical motion ensures efficient and even mixing and allows the unit to handle critical phases during drying.

Because the agitator design prevents the formation of agglomerates, no choppers or lump breakers are required. Such additions are undesirable, Comber notes, because they cause damaging shear and create dust during the final drying stage.

The agitator arms have large surface areas to maximize their effectiveness in their secondary role of heat or cooling the product. Heat transfer is also improved by narrow tolerances between the agitator and the vessel walls, which stop product sticking to the walls; this also makes the dryer easy to empty and allows it to be used with small batches.

Comber recently received an order for a large Condry unit with wetted parts of titanium. **www.comberscreening.com**

We protect systems from excessive pressure

Donadon SDD manufactures rupture discs, vent panels, and rupture indicators to high technical standards, yet boasts competitive prices and friendly, responsive service

The economical LPD low-pressure rupture disc from Donadon SDD...

Donadon Safety Discs And Devices (Donadon SDD) manufactures rupture discs, vent panels for explosion protection, and rupture indicating devices. To offer its customers a complete service the company also supplies a vast range of safety valves.

In the past six years, a new corporate structure has helped Donadon SDD evolve from an artisan firm into an industrial one. This change has been supported by important investments in R&D, manufacturing and testing equipment, and new premises.

Successful innovations include:

- Donadon SCR reverse-buckling and SCD forward-acting rupture discs, both of which feature six pre-scored sectors instead of the usual four to improve performance;
- Donadon LPD low-pressure rupture disk, a simple, reliable, accurate and cost-effective solution for applications such as storage tanks; and
- discs of titanium and tantalum, as well as stainless steel, nickel, Hastelloy, Monel, Inconel and graphite.

Compared to its competitors, Donadon SDD says it is small, flexible and responsive, without compromising on quality, as shown by the fact that the company is licensed to supply to nuclear power plants. A large percentage of internet sales aids direct technical contact with customers and keeps costs competitive. Standard delivery time is never more than three weeks, and in emergencies spares are supplied in a few days, with no surcharge.

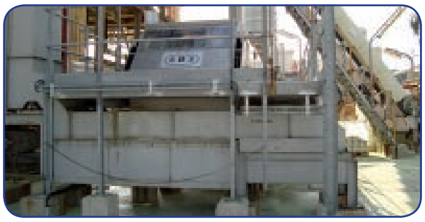
www.donadonsdd.com

...and the high-performance SCR disc

Circle 22 on p. 62 or go to adlinks.che.com/29246-22

Sulfur solidification plants

SBS Steel Belt Systems uses solid steel belts from Berndorf Band to process a wide range of materials. One important area of application is the pastillation of sulfur

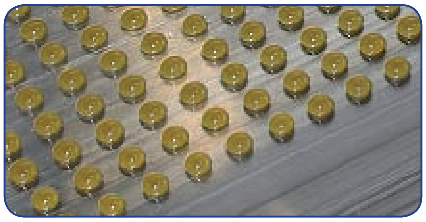


Sulfur pastillation line from SBS...

The Italian company **SBS Steel Belt Systems S.r.l.** (SBS) was established in 1984. Its main activity is to design and build continuous process conveyors, equipped with endless steel belts from Berndorf Band, for a wide range of applications in the chemical, petrochemical, plastic, food, rubber and powder coating industries.

SBS's premises are in Venegono Inferiore (VA), Italy. This site also houses a pilot-scale test center where SBS develops new industrial processes, either on its own account or in cooperation with customers.

The last few years have seen increasing demand for sulfur processing plants. In this industry sector SBS provides turnkey solutions based around cooling conveyors which solidify droplets of liquid sulfur into free-flowing pastilles. Sulfur pastilles produced on SBS equipment have a regular



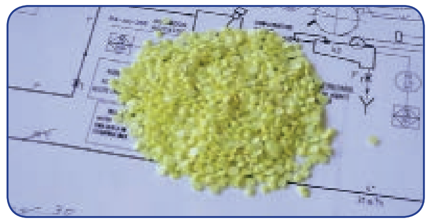
...sulfur pastilles on the steel belt...

hemispherical shape which makes for easy storage, packaging and metering. Ancillary equipment includes pumps to transfer liquid sulfur to the pastillator, and product handling equipment including silos, truck loading systems and automatic filling stations for big bags.

Each sulfur pastillating conveyor is provided with a hood to protect the working area. An exhaust fan carries sulfur dust and vapors to a ventilation manifold and duct which discharges outside the building. A second fan is permanently installed as a standby, and the hood has doors for inspection and maintenance.

Once solidified, the pastilles are discharged from the cooling belt onto a second conveyor. This then transports the pastilles to the next process step, typically a storage silo designed for loading trucks.

www.steelbeltsystems.it



...and free-flowing, dust-free product

The PLANEX System: Redefining vacuum drying

A brand new horizontal paddle vacuum dryer, equipped with an eccentric agitator with two independent movements, has been developed by ITALVACUUM

The PLANEX System is an innovative technology designed and patented by **ITALVACUUM**, which has manufactured vacuum dryers and vacuum pumps for the chemical and pharmaceutical industries since 1939. Especially suitable for the production of active pharmaceutical

Italvacuum's PLANEX System installed through the wall of a clean room

ingredients, fine chemicals and intermediates, the PLANEX System consists of a fixed cylindrical chamber containing an eccentric agitator with two independent rotations: the first about its own axis and the second tangentially to the chamber wall. This double motion ensures optimal mixing and continuous surface renewal, facilitating the release of solvent vapors and significantly reducing drying times.

Combined with the fact that the agitator is much smaller in diameter than the drying chamber, the double rotation also reduces mechanical stress. This prevents local overheating due to friction and allows the unit to treat even very delicate and heat-sensitive products. In fact, according to an independent analysis by Prof. M. Vanni and Eng. M. Garbero of the Material Science and Chemical Engineering Department at Turin Polytechnic, mechanical and thermal stress on the product is only one-third of that in a traditional dryer with a concentric agitator, and power consumption is correspondingly about one-third lower. The agitator shaft has a double mechanical seal for perfect vacuum tightness and zero contamination.

The narrow gap between the agitator and the wall of the drying chamber makes the unit easy to unload and to clean. An integral CIP system allows all parts in contact with the product to be washed down, and inspection is simple thanks to the large front port. The non-concentric agitator and easily-dismantled inner parts facilitate swab testing. To ensure external cleanliness there is no support frame within the sterile room; the drying chamber is simply flanged to the wall.

The PLANEX System is available in volumes of 300–4,400 l. Loading capacity is 15–80% of the vessel volume, depending on the product.

Through its recent introduction at Achema 2009, some industrial models of the Planex System have been already manufactured and a pilot unit for the execution of drying trials at the Italvacuum plant is available. **www.italvacuum.com**


essegiesse
Why Gamble?
With Pompetravaini, the high-tech Company, You can make the best choice.
pompetravaini
Our commitment is always to stay ahead
PFS PUMPS
Chemvac Pumps
pompetravaini spa
I-20022 Castano Primo (Mi) • Via per Turbigo, 44
Ph. +39.0331.889000 • Fax +39.0331.889057
sales@pompetravaini.it • www.pompetravaini.it
Circle 23 on p. 62 or go to adlinks.che.com/29246-23

Fighting corrosion in vapor recompression

New RBS positive displacement blowers from Robuschi are made from stainless steel. A prime application is in evaporators, where corrosion can attack cast-iron blowers

Robuschi has established a leading position in the markets for blowers and pumps, with an international reputation as an expert in customized solutions and systems. The company prides itself on its ability to respond quickly to changing needs, satisfying customers' specific demands at the lowest possible costs.

Recently Robuschi has broadened its product range through the launch of the new RBS positive displacement blower series in stainless steel. One of the main application for these blowers is in evaporation processes, where products are concentrated by adding energy to boil off a solvent, generally water.

To reduce the amount of energy used in evaporation, multi-effect and vapor recompression systems are very common. In the latter process, vapor removed from one stage of the evaporator is mechanically compressed, raising its enthalpy so that it can be re-used in the steam chest of the previous evaporator stage. The energy supplied to the compressor is an efficient way to add energy to the vapor and allow its latent heat to be re-used.

Positive displacement blowers are generally used for this application, but the presence of water droplets, often plus caustic chemicals and acids used to clean the evaporator tubes, can cause corrosion problems in ordinary cast-iron blowers.

The new Robuschi positive displacement blowers get around this issue by having their bodies and rotors made from AISI 316 stainless steel. The new stainless steel blowers are available for throughputs of 340–9,800 m^3/h and differential pressures up to 1,000 mbar. The machine has special labyrinth seals and, optionally, soft packing seals for easier maintenance. An adaptor kit for internal washdown is also available.

Mechanical vapor recompression is an effective way to operate evaporators with low specific energy consumption, high heat transfer rates, short product residence times, simple design and low running costs.

Now with the help of Robuschi stainless steel blowers, corrosion need no longer be a showstopper.

www.robuschi.com

Plants for surfactants and detergents

Desmet Ballestra has for many years been the leading supplier of surfactant and detergent plants, but also has a growing reputation in sulfuric acid and fertilizers

Desmet Ballestra SpA is the world leader in the design and supply of plants for surfactants and detergents. The company is a preferred technology supplier to all the major surfactant and detergent manufacturers worldwide, and has built no fewer than 1,600 plants in over 120 countries since it was founded in 1960.

Desmet Ballestra's film sulfonation technology has advantages over competing processes in terms of product quality, conversion rates, energy consumption, reliability, and maintenance costs. The company has built what are possibly the world's largest sulfonation plants, rated at 24,000 kg/h as 100% active surfactant.

With the addition of proprietary downstream processes for dioxane stripping and drying, Desmet Ballestra's sulfonation technology forms the basis of turnkey plants for detergent powder. These are available in capacities of 1–25 t/h as standard, with larger sizes on request.

Desmet Ballestra has recently launched a new alkoxylation process based on a state-of-the-art enhanced loop reactor developed jointly with alkoxylation experts Pressindustria and MFC Progetti. Compared to competing technology, the new process offers:

- higher reaction rates, thanks to improved heat and mass transfer;
- higher product quality, with consistent molecular weight and very low impurities;
- lower operating pressure;
- greater safety, due to the absence of rotating parts in contact with gas-phase alkylene oxides, and continuous wetting which prevents hot spots and avoids accumulation of alkylene oxides in the gas phase; and
- ability to produce high-molecular-weight alkoxylates (e.g. PEG) in a single step.

Besides its core business in detergents and surfactants, Desmet Ballestra is increasingly active in other fields, using technology developed in-house or licensed from well-known specialists such as UOP in petrochemicals and MECS for sulfuric acid. In the last few years the company has become well-known for integrated sulfuric acid plants with capacities of 100–2,000 t/d. These typically feature cogeneration of electricity and the latest MECS Heat Recovery System, which allows up to 93% of the available heat to be re-used.

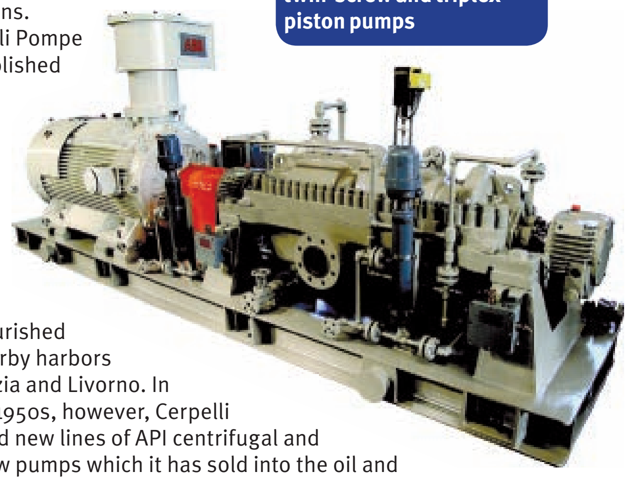
Global supplier: a 450 t/d Desmet Ballestra sulfuric acid plant in Egypt

Desmet Ballestra also supplies plants for LAB (UOP's Detal process), fertilizers (potassium sulfate and superphosphates), and detergent chemicals (sodium silicate, sodium sulfate, zeolite, sodium tripolyphosphate). **www.desmetballestra.com**

A wider range of pumps for oil and gas

Acquisition has helped the Finder Group expand in the hydrocarbons sector

The acquisition of Cerpelli Pompe, a historic name in the Italian pump industry, in the second half of 2008 has allowed the **Finder Group** to broaden its offering in pumps for oil and gas applications.



The HPMX centrifugal series: just one of Finder's broad range of API pumps for the oil and gas market. Finder also supplies API twin-screw and triplex piston pumps

Cerpelli Pompe was established in 1904. Initial production was mostly dedicated to the shipyard business which flourished in the nearby harbors of La Spezia and Livorno. In the early 1950s, however, Cerpelli introduced new lines of API centrifugal and twin-screw pumps which it has sold into the oil and gas industry ever since.

The acquisition brings to Finder Pompe new products to complement the company's existing catalogue in the petroleum business, as well as a long tradition of operations – and a large population of pumps installed – in Europe and in the Middle East. Cerpelli's larger test facility will also allow the Finder Group to test pumps of up to 2,250 kW.

The current Finder Group catalogue for the oil and gas market consists of API 610–ISO 13709 centrifugal pumps, API 676 twin-screw positive-displacement pumps and API 674 triplex piston pumps, the latter designed and manufactured by Finder's French subsidiary, Finder Pompes, under the PMH brand name.

This broad and complete range has allowed Finder Group to strengthen its position in the oil, gas and energy markets, and provided the opportunity for Finder to become a major partner for the main E&C companies worldwide.

Over the last 10 years, Finder Group has experienced a substantial growth in sales to the process, oil and gas markets. Besides an already well-established presence in petrochemicals, Finder has won important contracts for refinery, FPSO, upstream and platform applications worldwide, both directly with operating companies and via major EPC contracts.

For the future, Finder intends to continue its policy of investing to consistently upgrade both its production facilities and its products. This will be possible, says the company, thanks to an R&D department with an outstanding level of competence and experience.

The aim is to continue offering products of proven reliability, while keeping the flexibility which has allowed Finder to meet its customers' expectations by solving their application problems. Finder plans to increase sales and market share, with no loss of technical or creative flexibility.

www.finderpompe.com

Stratophase

JANUARY
New Products

Precision Polymer Engineering

MSA in Europe

Elga Process Water

Reduce rubber contamination in food with these elastomers

Detectaseal (photo) is a new, FDA-compliant, metal-detectable elastomer designed to help food companies reduce the risk of rubber contamination during processing. Detectaseal fragments as small as 2 mm can be identified by conventional inline metal detection equipment, ensuring early warning of rubber contamination. The seals are available as FDA-compliant grades of EPDM, nitrile and fluorocarbon elastomers, in blue and black, and in standard and non-standard sizes for use in a broad range of process equipment. — *Precision Polymer Engineering (PPE) Ltd., Blackburn, U.K.*
www.prepol.com

Ceramic membranes help filter surface-treatment effluents

This firm's new range of membrane plants for the surface-treatment industries feature CeraMem industrial strength membranes (photo). Compared to conventional polymeric membranes, CeraMem ceramic microfiltration (MF) and ultrafiltration (UF) membranes are less prone to fouling and have a greater resistance to high temperatures, as well as aggressive cleaning chemicals and abrasion. Membrane life is typically doubled, says the firm. The membranes are suitable for applications such as alkaline degreasing, cutting oil treatment and electro-coat paint treatment. — *Elga Process Water, Marlow, U.K.*
www.elgaprocesswater.co.uk

A family of products for WirelessHart communication

For the first time, this firm has developed products for WirelessHart communication. The new product family comprises two transmitters, a gateway to Industrial Ethernet and software, as well as an adapter for process instruments in preparation. Both the new Sitrans P280 pressure transmitter and the Sitrans TF280 temperature transmitter (photo) feature a WirelessHart interface and a graphical display with backlight function. All other process instruments from this firm that do not have WirelessHart interfaces can be integrated into WirelessHart communication with the Sitrans AW200 adapter. Finally, the new IE/WSN-PA Link gateway manages the WirelessHart network with all the nodes and establishes the connection to the Simatic-based automation and control system via Industrial Ethernet. — *Siemens Industry Automation Division, Nuremberg, Germany*
www.siemens.com/industry

Siemens Industry Automation

Monitor fermentation in realtime with this probe

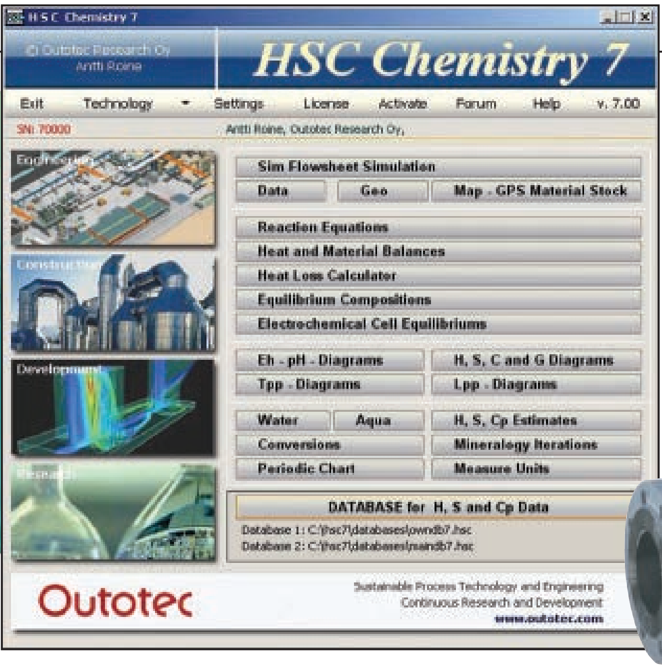
Developed in collaboration with the Center for Process Innovation (Wilton, U.K.), the Insertion Probe variant of this firm's SpectroSens system enables realtime monitoring of bioproduction fermentation processes. The multi-output SpectroSens Insertion Probe (photo) tracks compositional changes and monitors temperature in the liquid. Multiple discrete readings can be taken simultaneously at numerous locations, providing more reliable measurements and a reduced chance of false positives. Using only light at the point of measurement, the sensors are intrinsically safe and spark-free. — *Stratophase, Romsey, U.K.*
www.stratophase.com

A new version for this flowsheet simulation software

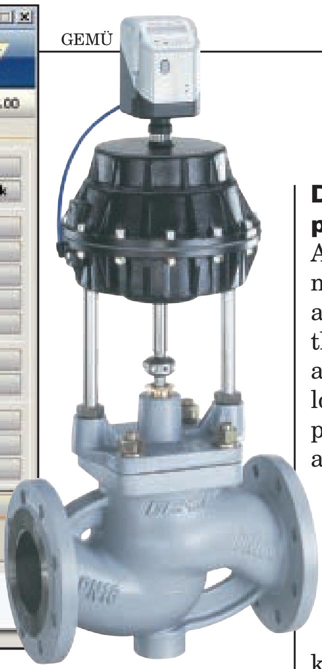
The new HSC Chemistry 7.0 is a straightforward simulation tool (photo, p. 24I-13) designed to guide process-development and research scientists. Compatible with Windows Vista, Vista

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

Outotec Research



GEMÜ



64 and Windows 7, HSC Chemistry 7.0 is a software program for process flowsheet simulation, which also contains 22 other calculation modules displayed as options in the main menu, and 12 databases together with extensive thermochemical, heat transfer and mineralogical data. The Flowsheet Module has four different modes: particles, reaction, distribution and experimental. The new Unit Icon Library comprises 515 high-resolution icons that have been created to visualize process flowsheets. — *Outotec Research Oy, Pori, Finland*
www.outotec.com/HSC

Disposable respirators for protection against aerosols

Affinity FLS (photo, p. 24I-12) is a new generation of foldable disposable respirators. Its high-performance thin and light filtering media provide a comfortable fit even when used for longer periods. Affinity FLS offers protection against penetrating solid and liquid aerosol particles. Meeting requirements of EN 149:2001, the different types of masks conform respectively to protection levels FFP1, FFP2 and FFP3. A color-coding system ensures easy identification and helps the user to select the correct kind of mask for a given application. — *MSA in Europe, Berlin, Germany*
www.msa-europe.com

This globe valve now comes in smaller sizes

The GEMÜ 520 actuated globe and control valve (photo) is particularly suitable for handling steam, air,

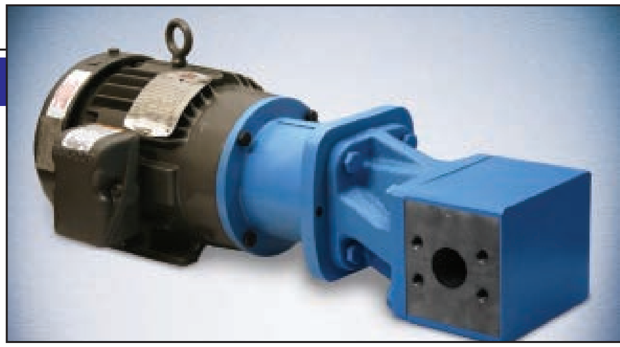
water and process lines on account of its membrane actuator. The existing sizes DN 65–150 are now extended to smaller nominal sizes DN 32–50. New actuator-valve body versions have also been developed to expand the range of applications. In DN 32–65, the valve can be used with operating pressures up to 40 bar with valve bodies in cast steel GP 240 H and stainless steel 1.4408. Other new options include valves that can be actuated with a considerably reduced control pressure of 1.5–4 bar. — *GEMÜ Gebr. Müller Apparatebau GmbH & Co. KG, Ingelfingen-Criesbach, Germany*
www.gemue.de

A wide range of gear pumps gets extended even more

The established range of Viking External Gear Pumps (photo) has been extended to include models that provide flows from as little as 0.2 L/min up to 760 L/min. Available from this firm, the SG range now includes 29 models, and includes models rated for maximum continuous pressures of up to 34 bar and maximum intermittent pressures up to 172 bar. As a result of the wide range of models, configurations and material options, Viking SG Series Gear Pumps are suitable for applications such as centralized lubrication systems; polyurethane metering and mixing; compressor lubrication; burner feed; pipeline sampling; heat transfer; and adhesive and sealant dispersion. — *Michael Smith Engineers Ltd., Woking, U.K.*
www.michael-smith-engineers.co.uk

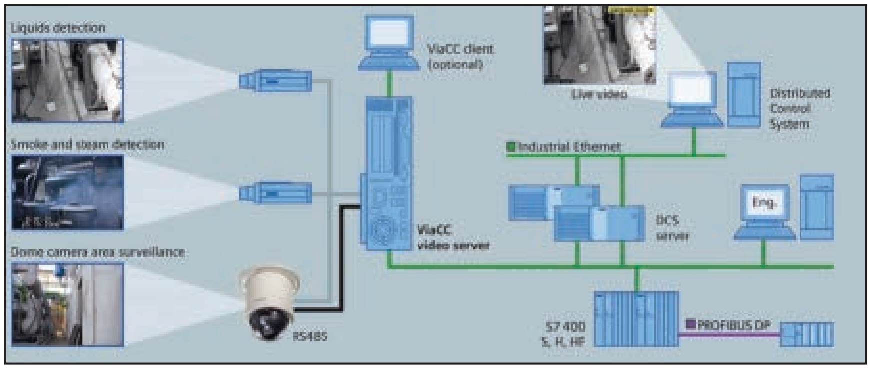
Conductive plastic pumps for safe transfer operations

Available in March, the SCP-6500 Pumps (photo) feature a lug with a grounding wire on the front of the pumps, and made with conductive plastic, these pumps allow users of flammable liquids to ground the pumps, making them safe for use with Class 1 and Class 2 flammables. All components of this pump that come in contact with the fluid are created with conductive plastic, so there is grounding of the liquid, the pump and, with correct bonding, the container. — *GoatThroat Pumps, Milford, Conn.*
www.goatthroat.com



Michael Smith Engineers

GoatThroat Pumps



Siemens Industry Sector

Spot leaks with this video-based software

ViaCC is a video-based software that quickly and effectively detects leaks in an industrial environment. This software-based sensor is an extension to conventional sensors, and enables recognition of smoke, fumes, leaking liquids and colors. ViaCC software contains detection methods that can be freely combined and that are suitable for detecting edges, colors, movements and so on. Up to twelve cameras record and transmit about 200 images per second to each server (photo). The automation state and the live situation are directly coupled, which enables process data to be inserted directly into a video image and saved. Live images of a fault enable service to be better planned with appropriate spare parts and tools. — *Siemens Industry Sector, Industry Solutions Div., Erlangen, Germany*
www.siemens.com/industry

A coupler for increased hose maneuverability

The patented Variacor coupling (photo, p. 24I-15) provides free orientation for hydraulic and pneumatic hoses and tools across a wide range of applications. The design of the coupling ensures optimum flexibility, which results in less wear on hoses. Also, increased maneuverability of the hose means easier handling for the user, with lower pressure and flow losses compared to conventional couplings, says the firm. The Variacor coupling is ideal for connecting two runs of rigid pipe or flexible hoses, or an end fitting, such as a nozzle or gun. It can be used for changing the angle of flow direction, axially between 180 and 90 deg, with full 360-deg swivel at either or both ends. — *Bete Ltd., Lewes, U.K.*
www.beteuk.com

This sensor monitors a wide range of conductivities

The tecLine LF-4P (photo, p. 24I-15) is a new cell with four-pin technology for measuring conductivity. The device fills the gap between two-electrode cells and inductive measurement technology, and makes it possible to cover a very wide measurement range from about 1 µS/cm to 600 mS/cm. The cell consists of a sturdy PEEK plastic body with stainless-steel electrodes inserted into the front. An integrated Pt1000 temperature sensor provides the signal needed for temperature compensation. The cell is available in different fitting lengths. — *JUMO GmbH & Co. KG, Fulda, Germany*
www.jumo.net

A new diaphragm seal for homogenization processes

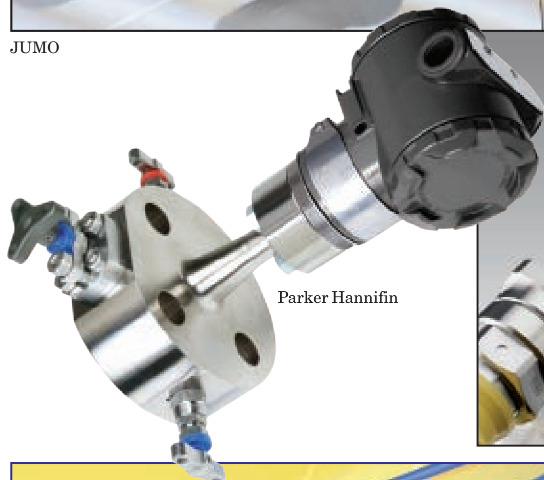
The Model 999.30 diaphragm seal is available in combination with an intelliGauge Series mechatronic pressure gauge (photo, p. 24I-15). The

Bete

JUMO

WIKA Alexander Wiegand

VEGA Grieshaber



Parker Hannifin

diaphragm seal is tailor-made for the extremely dynamic homogenization process. The damped instrument is designed for a static pressure of up to 2,500 bar. The combination with the intelliGauge provides a local display via a bourdon-tube pressure gage and an electrical output signal without the need for an external power supply. — *WIKA Alexander Wiegand SE & Co. KG, Klingenberg, Germany*
www.wika.de

A large-bore needle valve for viscous, contaminated media

A new 0.5-in. bore instrumentation needle valve (photo) gives plant engineers the means to improve reliability, and save both money and space in process and instrumentation applications involving viscous and contaminated media. The new H-Series needle valve is available as either a discrete hand valve for controlling media flow, or integrated into a monoflange-style manifold for the safe "double-block-and-bleed" connection of instruments to process lines. The large flow path of the 0.5-in. H-Series needle valve makes it less prone to blockage, and its metal-to-metal seal provides a bubble-tight seal over a temperature range from –55 to 538°C. — *Parker Hannifin, Instrumentation Products Div. Europe, Barnstaple, U.K.*
www.parker.com

Track air flow in larger pipes with these sensors

This firm's ATEX-certified flow sensors for gaseous media are now available with probe lengths of 100, 140 and 220 mm. The new extended probes (photo) significantly enhance the sensors' functionality by allowing users to install the sensors in pipes with diameters of up to 440 mm. The IP67 stainless-steel sensors are certified for gas zone 1, and can be installed in the tube via a T connector. The sensors detect flow status of gaseous media, such as air, by evaluating the flow-induced temperature difference between the heated probe and the medium. — *Hans Turck GmbH & Co. KG, Mülheim an der Ruhr, Germany*
www.turck.com

Hans Turck

Emerson
Process Management

Detect level of bulk solids without making direct contact

The microwave barrier Vegamip 61 (photo) is designed for the requirements of the bulk solids industry. The microwave barrier measures without making direct contact with the medium, which is particularly advantageous when dealing with abrasive materials or very high temperatures. The device measures from the outside through a microwave-permeable window made of ceramic or plastic. The barrier consists of a Vegamip T61 transmitter and one or several Vegamip R61 receivers. The receiver measures the attenuation of the microwave signal, and generates a switching signal from it. The device can be used as a maximum- or minimum-level sensor. — *VEGA Grieshaber KG, Schiltach, Germany*
www.vega.com

Wet chemistry moves into the process for online monitoring

The Rosemount Analytical online wet-chemistry analyzers for sodium (photo), silica, phosphate, hydrazine

and ammonia are used for process monitoring in the power and ultrapure water industries. The analyzers are easy to use. Pressing one button starts, calibrates and puts the instrument online. Routine reagent replacement and maintenance takes only 5 min every three months, and replacing the valve pump — the heart of the analyzer — takes about 15 min every two years. The addition of wet chemistry analyzers (acquired from Scientific Instruments Inc. in May 2009) complements this firm's line of conductivity, pH and dissolved oxygen sensors and analyzers. — *Emerson Process Management, Baar, Switzerland*
www.emersonprocess.eu

Sample or dose reactors with this syringe pump

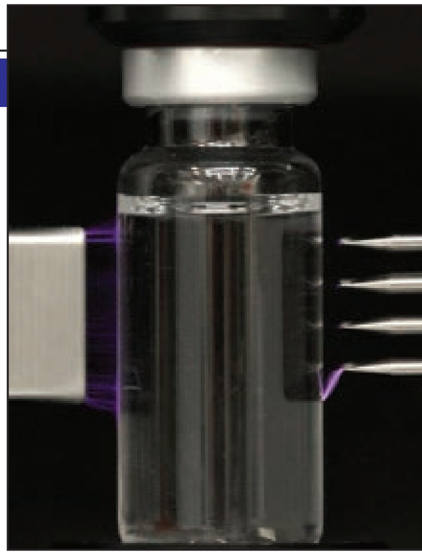
The Atlas Syringe Pump XL is a volumetric dosing or sampling system consisting of two syringes, with up to six port valves. Each syringe can aspirate or dispense independently from any valve port, allowing dosing of one reagent to many reactors, or many reagents to one reactor. With a flowrange of 5 µL/min up to 100 mL/min, it can be configured either into two refilling flows or one continuous flow, providing reaction sampling, advanced pH control and temperature-dependent dosing. — *Syrris Ltd., Royston, U.K.*
www.syrris.com

Track product color and gloss without making contact

The VS450 non-contact spectrophotometer (photo) is designed for color and gloss measurement on wet and dry samples, including cosmetics, paints, soil, plastics and powders. The device features an integrated gloss sensor for relative gloss measurements, and when used with iMatch formulation software, provides wet-to-dry correlation for improved quality control and formulation throughput. — *X-Rite Europe GmbH, Regensdorf, Switzerland*
www.xrite.com

A valve positioner package for large actuators

The air output capacity required to achieve fast positioning in large actuators (diaphragm areas of 1,400–2,800 cm^2) is too much for normal positioners, and so positioning accuracy can be compromised. A solution to this problem is a control-valve positioner package (photo), which facilitates exact positioning with fast response times over the entire operating range. The package consists of a positioner and a hook-up of several volume boosters with different output capacities. Closing and opening times of less than 2 s can be achieved over the entire positioning range. The package has proven itself for compressor bypass valves (anti-surge valves) and in petrochemical applications involving moving-bed adsorption processes. — *Samson Controls (London) Ltd., Redhill, U.K.*
www.samsoncontrols.co.uk


Seidenader Maschinenbau

Fast, wireless data transfer with this adapter

The new Bluetooth Ethernet Port Adapter FL BT EPA AIR SET is a rugged and reliable "wireless Ethernet cable" to transfer control data to machine units that are either moved frequently or are mobile in industrial environments. The newly developed Bluetooth Lean Stack and the priority assignment functions permit fast, Profinet and Profisafe wireless data transfer with uptimes of 8 ms. — *Phoenix Contact GmbH & Co. KG, Blomberg, Germany*
www.phoenixcontact.com

Inspect vials visually and with high voltage

Said to be the first implementation of visual inspection and high-voltage crack detection combined in a single machine, this module inspects vials and pre-filled syringes for cracks and leaks. A precise handling system orients the containers at an angle of 90–110 deg to at least four high-voltage electrodes (photo), which allows the detection of cracks that have fully penetrated the glass while ignoring surface scratches. The High-Voltage module is fully integrated in the company's VI and MS families of inspection machines, allowing camera inspection before high voltage inspection. Only products that passed all camera inspections undergo the check for cracks. — *Seidenader Maschinenbau GmbH, Markt Schwaben, Germany*
www.seidenader.de

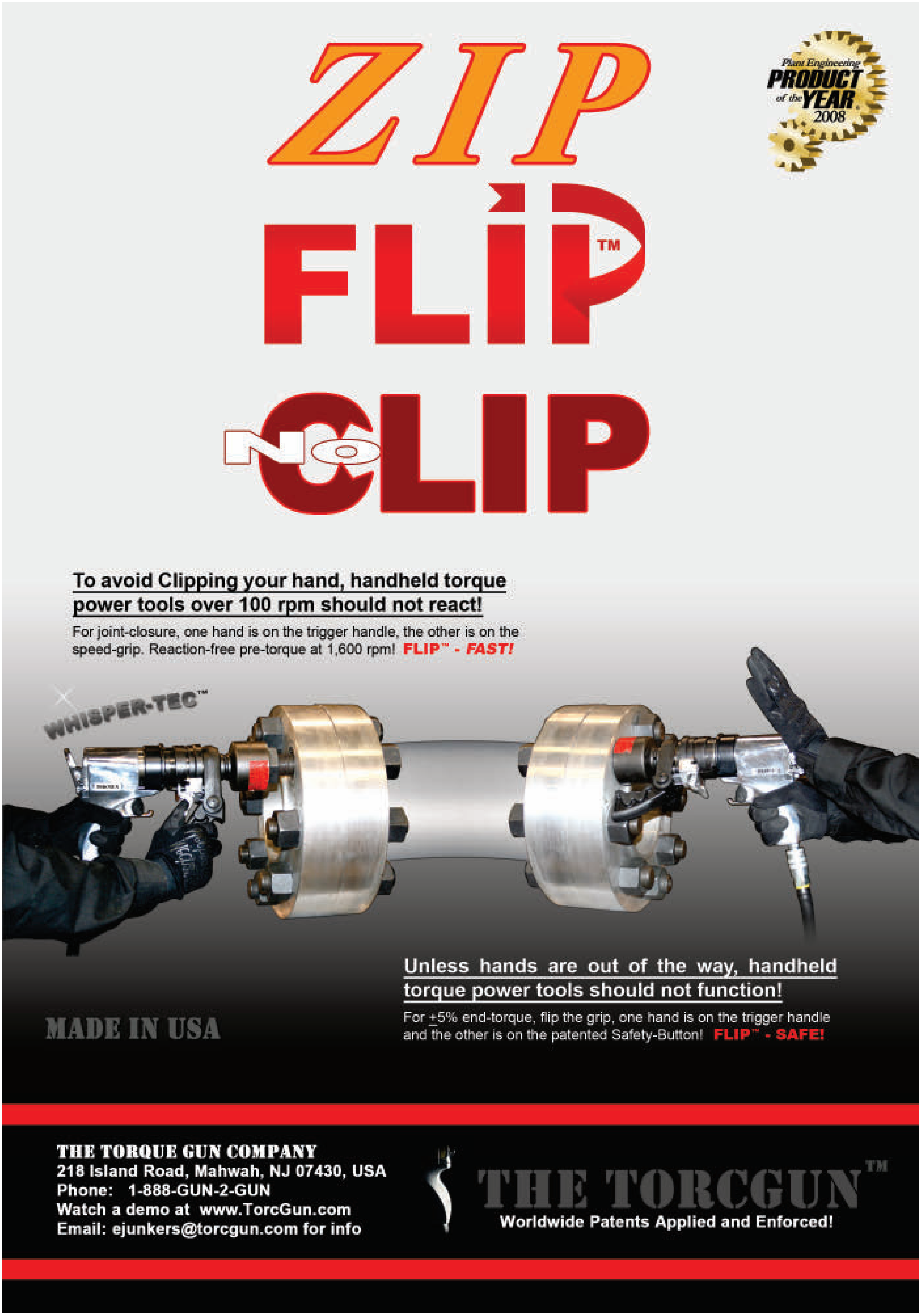

X-Rite Europe


Samson Controls

An accurate way to feed large quantities of bulk materials

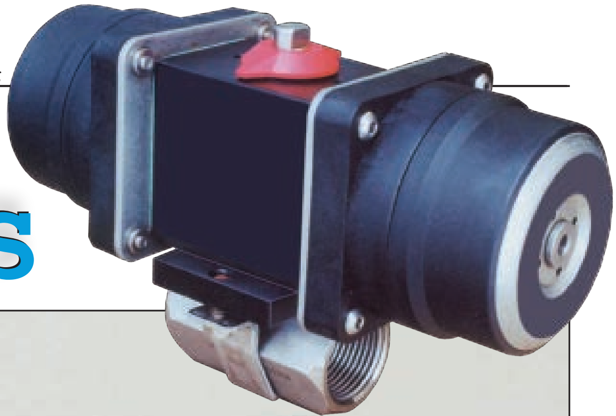
The Model 26C Vibratory Feeder is a rugged, a.c.-operated unit that enables linear, exact feeding of large quantities of bulk materials. These electromagnetic feeders offer a cost-effective, sanitary alternative to screw feeders, says the manufacturer. The Model 26C is designed for feeding up to 4 ton/h, and features a totally enclosed, dust- and moisture-resistant, patented electromagnetic drive, which extends the core life and makes cleaning easier. — *Eriez, Erie, Pa.*
www.eriez.com ■

Gerald Ondrey



Circle 29 on p. 62 or go to adlinks.che.com/29246-29

JANUARY New Products



Omega Engineering

ITW ActiveTouch

Parker-Hannifin

Fairchild Industrial Products

Argonide

Protect braided hoses with these sleeves

This company offers heat-shrink coverings (photo, top) to protect process hoses both from contamination and overall wear and tear. Their colors can be used as a code to help identify hoses. Also from this firm are fire sleeves (photo, bottom), which are sized to fit and maintain the outer hose temperature for safer handling. Hose coverings are offered in sizes from 0.25 to 1.25 in. — *Parker-Hannifin Corp., Fort Worth, Tex.*
www.pageintl.com

Harsh environments will not harm these pressure transmitters

The TD8600 and TA8800 Series (photo) precision pneumatic-to-current pressure transmitters are designed for harsh applications such as tire manufacturing, pulp and paper, test equipment and factory automation. They can be used with either pneumatic or hydraulic systems. The TD8600 Series offers 0.5% accuracy and has a hermetically sealed housing that is constructed from laser-welded stainless steel. For applications requiring greater accuracy, the TA8800 offers 0.2% or better accuracy in a similar stainless-steel housing. A wide variety of options are available, including special electrical connectors, optional pressure ports, temperature compensation and exotic wetted materials. — *Fairchild Industrial Products Co., Winston-Salem, N.C.*
www.fairchildproducts.com

Conductive plastic pumps for safe transfer operations

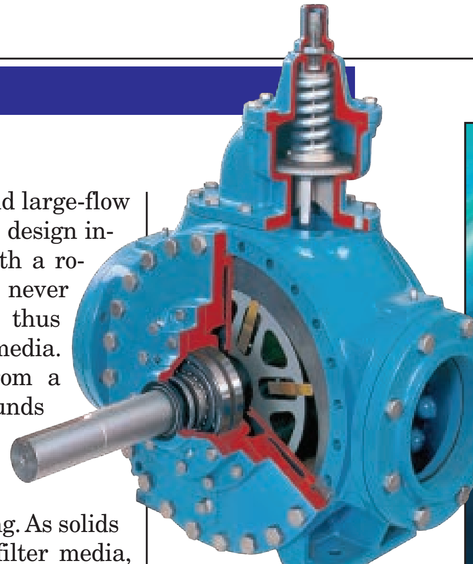
Available in March, the SCP-6500 Pumps feature a lug with a grounding wire on the front of the pumps, and made with conductive plastic, these pumps allow users of flammable liquids to ground the pumps, making them safe for use with Class 1 and Class 2 flammables. All components of this pump that come in contact with the fluid are created with conductive plastic, so there is grounding of the liquid, the pump and, with correct bonding, the container. — *GoatThroat Pumps, Milford, Conn.*
www.goatthroat.com

Remove suspended solids to 10 microns with this filter

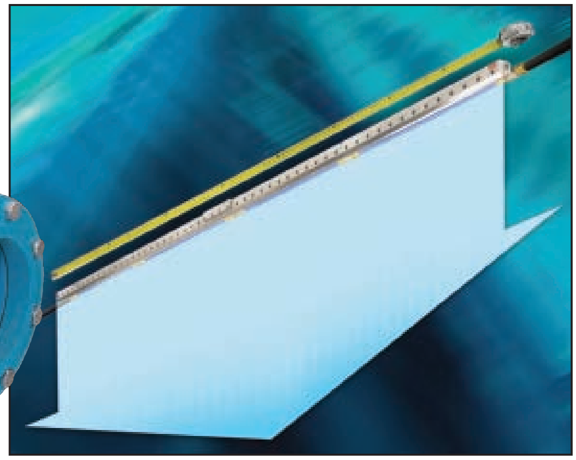
FlowTex is a high-performance tertiary filter that removes suspended solids as small as 10 microns, and is

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

suitable for both small- and large-flow applications. The patented design incorporates a fixed disc with a rotating suction head that never touches the cloth media, thus extending the life of the media. Flow enters the filter from a pipe and completely surrounds the discs. Turbulence from the incoming wastewater keeps solids suspended and prevents premature settling. As solids accumulate on the cloth filter media, the flow becomes restricted, causing the liquid level to rise. Backwashing is automatically triggered when the level reaches a predetermined point. A vacuum head then rotates across the surface of the disc, removing captured solids from the media. — *Entex Technologies Inc., Chapel Hill, N.C.*
www.entexinc.com



Blackmer Pump



Exair

Replace lenticular filters with these cartridges
NanoCeram-LR high-performance pleated filter cartridges (photo, p. 24D-2) have been specifically designed and engineered as drop-in replacements for lenticular filters. They will fit most commercial lenticular housings, and are said to show greater dirt-holding capacity, higher efficiency and wider operating pH range versus other charged lenticular filters. Each NCLR incorporates the patented non-woven filter media matrix infused with nano-alumina fibers, creating an electropositively charged depth filter. NanoCeram is capable of removing small particles (including colloidal iron), bacteria and viruses from water at high flowrates. Silt density index (SDI) values averaging less than 0.5 and turbidity levels less than 0.01 NTU are achieved. — *Argonide Corp., Sanford, Fla.*
www.argonide.com

Unbreakable switch technology finds application in keyboards
ITW ActiveMetal switches (photo, p. 24D-2) have been introduced to this firm's ActiveTouch line of switch products. The patented pushbutton switch employs a low-voltage subminiature transducer, which generates megahertz frequency vibration to the pushbutton a thousand times per second and detects the decay (or ringdown) of that vibration. When the button surface is touched by a bare finger or gloved hand, the ultrasonic vibration is dampened and the transducer detects the change within milliseconds. Firmware built into the printed circuit board of the transducer includes the capability to identify and predict problems, such as foreign material interference within the switch area, and adapts to the change. One of the first applications is a standard QWERTY keyboard for use in sterile environments. — *ITW ActiveTouch, Buffalo Grove, Ill.*
www.itwactivetouch.com

Stainless-steel external trim is standard with these ball valves
The compact, light-weight BVP70/BVP80 Series of actuated ball valves (photo, p. 24D-2) feature a stainless-steel external trim and FKM O-rings as standard. The series is designed to operate using an air supply in the range 50–125 psi. The direct valve-stem coupling to actuator shaft minimizes backlash, says the manufacturer. Electric actuators feature two 1/2 NPT conduit ports and integral thermal overload protection. — *Omega Engineering Inc., Stamford, Conn.*
www.omega.com

Use this pump to evacuate liquid storage terminals
HXL sliding vane pumps (photo) are designed specifically to rapidly and efficiently evacuate product from large liquid storage terminals, enabling fast product changes that react to market opportunities. The pumps can handle large volumes of a wide range of noncorrosive liquids, from thin solvents to heavy oils. Strong suction-lift capability efficiently transfers products from barge or ship into storage tanks while efficiently stripping both suction and discharge lines to minimize product loss. The HXL pumps feature self-adjusting vanes, which eliminate slippage caused by normal wear, and the capability to self-prime. so they are always ready to operate without time-wasting priming routines, while an internal relief valve protects against excess line pressure. HXL models are available in 6-, 8- and 10-in. sizes with operating speeds up to 350 rpm and maximum rated capacities of 755, 1,228 and 2,300 gal/min, respectively. — *Blackmer Pump, Grand Rapids, Mich.*
www.blackmer.com

This back pressure regulator is designed for ultra-low flowrates
The LF Series back pressure regulators can perform over a wide 10,000:1 flowrate window and can handle pressures between 0.02 and 2,000 psig. The instruments are ideal for instrument and gas analysis applications and can operate with valve flow coefficients as low as $1x10^{-7}$. These regulators solve chatter and low-flow stability problems in many gas research applications, including gas chromatography. They can exhibit low-flow precision well below 1 mL/min. The body is constructed of stainless-steel 316, and the regulators are available with three different types of diaphragms, SS316, PTFE, and Viton. — *Equilibar LLC, Fletcher, N.C.*
www.equilibar.com

This airflow source can reach surfaces up to 96-in. wide
Long Super Air Knives (photo) pro-

duce a laminar sheet of airflow to dry, cool or blowoff surfaces up to 96-in. wide. The blowers feature a compact design with no moving parts and that minimizes the use of compressed air. It is ideal for use on wide industrial parts, webs and conveyors. The Long Super Air Knives produce a uniform, high-velocity and high-volume curtain of air that is fully adjustable from a gentle continuous flow to a hard-hitting blast. Long Super Air Knives are available in four sizes — 60, 72, 84 and 96 in. — and can be constructed from aluminum or stainless steel. — *Exair Corp., Cincinnati, Ohio*
www.exair.com

This level sensor is based on magnetostrictive technology

Launched last month, the H-Series hard-wired continuous level sensors complement this firm's existing wireless liquid-level transmitters. The H-Series is a digital level sensor based on magnetostrictive technology, which makes it ideal for oil and gas, food and beverage and other applications that require process control, leak detection or inventory control. With a low-power design, the H-Series sensors can be multi-dropped on a RS 485 network, providing Modbus connectivity to a RTU or PLC controller. The sensor delivers high resolution (0.01 in. across full span) and is capable of providing product level, interface level and temperature measurement in virtually all tank sizes (up to 60 ft. tall) on a variety of liquids, such as crude oil, solvents, water, diesel, kerosene and gasoline. — *OleumTech Corp., Irvine, Calif.*
www.oleumtech.com

Specialty motors certified for hazardous duty

This firm's P/N 122055-00 (114587) and 122056-00 (114589) hazardous-duty vacuum motors have recently passed the final audit for TÜV/ATEX certification. The motors are 7.5-in.-dia., two-stage, peripheral bypass vacuum motors. The single-phase, two-pole universal motor series is totally enclosed, externally fan-cooled. That motor is combined with a centrifugal blower to produce vacuum airflow characteristics suited for vacuum-blower applications. The motors are available in both 120- and 230-V a.c. models and incorporate class B insulation in the armature and field windings. — *Ametek Floorcare & Specialty Motors, Kent, Ohio*
www.ametekfsm.com

Spot leaks with this video-based software

ViaCC is a video-based software that quickly and effectively detects leaks in an industrial environment. This software-based sensor is an extension to conventional sensors, and enables recognition of smoke, fumes, leaking

Cleveland Vibrator

liquids and colors. ViaCC software contains detection methods that can be freely combined and that are suitable for detecting edges, colors, movements and so on. Up to twelve cameras record and transmit about 200 images per second to each server. The automation state and the live situation are directly coupled, which enables process data to be inserted directly into a video image and saved. Live images of a fault enable service to be better planned with appropriate spare parts and tools. — *Siemens AG, New York, N.Y.*
www.siemens.com/industry

This vibrator has permanently lubricated bearings

The new CVT-P-22 Mini Turbine Vibrator (photo) delivers twice the force outputs of other miniature models above 50 psi. Constructed with an acetal plastic and stainless-steel exterior parts, the vibrator is suitable for cleanroom environments and is U.S. Food and Drug Administration- and U.S. Department of Agriculture-compliant for food applications. The vibrator has permanently lubricated bearings and operates from 10 to 100 psi. At 80 psi, the product generates 18,000 vibrations per minute with a 55.2-lb_f force output, while consuming 2.0 ft^3/min of air. The device is designed for food and pharmaceutical applications, such as powder filling, hopper-flow assistance and tablet packaging. — *Cleveland Vibrator Co., Cleveland, Ohio*
www.clevelandvibrator.com

Blue- and white-light LEDs provide illumination for this scope

The CB-400 Cobra-4 borescope (photo, p. 24D-8) features a dual head blue- and white-light LED (light-emitting diode) to allow technicians to inspect and check for leaks in hard-to-see components without disassembly. The blue LED is designed for fluorescent leak detection while the white light is ideal for component inspection. The Cobra-4's shaft is 4-mm wide and 36-in. long, and it comes with an angled inspection mirror and three AAA alkaline batteries. — *Spectronics Corp., Westbury, N.Y.*
www.spectroline.com

Disposable respirators for protection against aerosols

Affinity FLS is a new generation of foldable, disposable respirators. Its high-performance thin and light filtering

Quadro Engineering

media provides a comfortable fit even when used for longer periods. Affinity FLS offer protection against penetrating solid and liquid aerosol particles. Meeting requirements of EN 149:2001, the different types of masks conform respectively to protection levels FFP1, FFP2 and FFP3. A color-coding system ensures easy identification and helps the user to select the correct kind of mask for a given application. — *Mine Safety Appliances Co., Pittsburgh, Pa.*
www.msanorthamerica.com

Screen, delump and discharge without feeder equipment

The FlexSift S10 (photo) is said to enable higher capacities and better product flow than conventional sifters because of its ability to screen, delump and discharge solids without the need for feeder equipment. Constructed with minimum number of parts, the FlexSift S10 is designed for easy clean-up and faster screen maintenance. The S10 can be readily coupled with most bulk bag unloaders and mixer dischargers, and can be customized to suit many applications. The vibration-free design of the S10 lowers noise, and reduces power and maintenance. — *Quadro Engineering Corp., Waterloo, Ont.*
www.quadro.com

This monitoring system can operate with solar power

The WIPAT Remote Patrol and Monitoring System is a long-range, drop-in-place wireless video monitoring system that has the option of operating on solar power. The monitoring system is designed for use in electric power installations, oil and natural gas pipelines, water and wastewater treatment plants and public infrastructure areas. It can provide video clips, still images, event logging and access control, and its configuration allows large-scale networking and integration with common industrial control hardware and software. With solar power and satellite connections, WIPAT can operate without reliance on phone lines or fiber optic cable. — *Satel-West, Cupertino, Calif.*
www.satel-west.com

A new hygrometer is built for easy portability

The Optidew Transportable is a dew-point hygrometer that operates on the optical dew-point measurement principle and is easily portable. It is designed for drift-free measurement of the performance of desiccant dehumidifiers in a number of applications. Housed in a specially designed case, the small and lightweight instrument is fully self-contained. The instrument offers a wide measurement range, from the equivalent of less than 0.5% up to 100% relative humidity, and features a high-definition alphanumeric display that shows the measured humidity, dew point, water activity and other hygrometric variables. — *Michell Instruments Inc., Rowley, Mass.*
www.michell.com/us

This water quality system has a smart controller

The G Series water quality system, based on reverse osmosis (RO) membranes, operates with this company's Smart Controller technology, which monitors the performance of the equipment, stores historical operating data and alerts users of water quality or system issues. Smart Controllers are easy to install and can operate independently or linked to control room equipment. The G Series RO products are said to eliminate 98% of dissolved minerals, particles and organics from water for applications such as improving the taste of drinking

New Products

Fluke

water, decreasing scaling in boilers, humidifying, washing and water reclaiming. — *Culligan International Co, Rosemont, Ill.*
www.culligan.com

Spectronics

This lubricant is ideal for heavy-duty applications

Silicone Lube is designed to provide lubrication and protection on a wide range of surfaces in heavy-duty applications. The product is highly concentrated and is said to extend the life of metal, plastic, wood, rubber, vinyl and more by eliminating the sticking, binding and squeaking caused by constant friction. Silicone Lube is non-staining and is suitable in areas where chlorinated, solvent-based alternatives may be too harsh. It protects from moisture, and dries tack-free. — *B'laster Chemical Co., Valley View, Ohio*
www.blasterproducts.com

The pressure range of this gage has expanded

The PPC4 pressure controller (photo) and calibrator has an expanded pressure range, 0.15 psi to 2,000 psi, including gage-pressure equivalents and low-pressure differentials. It is designed for testing pneumatic pressure instruments in calibration laboratories and manufacturing environments. The PPC4's graphical interface supports 11 languages. It is said to be durable enough for mobile applications and standard shipping. — *Fluke Corp., Everett, Wash.*
www.fluke.com

A wireless adapter allows access to HART data

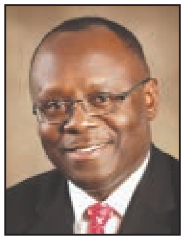
The wireless THUM adapter helps users see diagnostics and process information that had been inaccessible with wired legacy HART (highway addressable remote transducer) protocol instruments. Upgrading devices with the THUM adapter can avoid the expense and complexity of accessing HART data through traditional wired means. The THUM adapter is a wireless device that can retrofit on almost any two- or four-wire HART device, without special power requirements, to enable wireless transmission of measurement and diagnostic information. THUM adapters extend predictive intelligence into new areas of the plant, and are said to offer new opportunities for process improvements. With the THUM adapter, users can transform any HART instrument into a wireless device to enable expanded visibility in applications such as tank gaging, radar level, ultrasonic level, flow, valves, liquid and gas analytical, pressure and temperature. — *Emerson Process Management, Marshalltown, Iowa.*
www.emersonprocess.com ■

Scott Jenkins

WHO'S WHO

Sharp

Vaughan



Ezeuzoh

Fleming

Borghoff

Robert (Bob) T. Sharp is named president of **Emerson Process Management, Europe** (Baar, Switzerland).

Paul MacGregor, vice-president of operations and project services for TransCanada Pipelines, Ltd. is elected chair of the **Pipeline Research Council International** (Arlington, Va.).

Miriam Cortes-Caminero becomes executive director of **AIChE's Society for Biological Engineering** (New York).

Foster Wheeler AG (Zug, Switzerland) appoints *Clive Vaughan* CEO, Upstream Oil and Gas Group, in the company's global engineering and construction group.

EagleBurgmann U.S. (Houston) names *Philip Peck* sales director, and *Patrick McCann* manager of service center operations.

ChemLogix, LLC (Blue, Bell, Pa.) promotes *Francis Ezeuzoh* to CFO.

Shaun Julian is appointed account manager at specialty fluorochemicals producer **Halocarbon Products Corp.** (River Edge, N.J.).

Polymer additives maker **Songwon Industrial Co. Ltd** (Ulsan, Korea) appoints *Peter Fleming* sales director for the Middle East and Africa.

Thomas Borghoff becomes managing director of sales for **The Beumer Group** (Beckum, Germany), a manufacturer of conveying, palletizing and packaging systems. ■

Suzanne Shelley

Capital And Production Costs: Improving the Bottom Line

Thane R. Brown
Universities of Dayton and Cincinnati
(Retired from Procter & Gamble)

Decisions made in early phases of a project affect production costs for years to come. The disciplined method described here taps into potential savings

The chemical process industries (CPI) invest large amounts of capital each year and spend even more to produce the goods they sell. In 2007, CPI companies large enough to be in the Fortune 500 list invested more than $100 billion of capital and spent more than $1.2 trillion making their products. Most of this money is committed by decisions made in the early stages of process development and plant design. This article presents a disciplined method, called Economic Design, for decision making, early on in a project, that can lead to significant savings for many years.

To demonstrate the size of investments being discussed, the CPI companies referred to above are listed in Table 1 along with their 2007 capital investment and cost of the products made (see the "Cost of Products" box for further explanation). While this list does not include smaller companies, it does capture the majority of capital and production costs spent in these industries. As mentioned, most of this money is committed as soon as engineers make key decisions during product development, process development and the feasibility and conceptual phases of plant design. Often, their decisions have longterm, lasting impact as shown in these examples:

- Deciding to use a high-purity raw material commits a company to higher raw material costs than does the selection of a lower grade material. However, use of a lower grade material could require added processing to clean up that material or to process recycle streams caused by the lower grade material. Either way, the company's raw material cost structure gets set.
- Deciding to manufacture a raw material rather than buy it forever changes a company's capital and production cost structure.
- Deciding to build a batch rather than a continuous process has ongoing, unchangeable capital- and production-cost ramifications.
- On a smaller scale, selecting a positive displacement pump instead of an ANSI centrifugal pump results in permanently higher capital, depreciation and maintenance costs.

Over the years, I have observed and worked with many different project teams on all sizes of projects. What I learned is that the capital and production costs are very dependent upon the amount of attention the project leader and the design team pay to costs. Teams with a high level of cost discipline had lower costs and vice versa. From that, I concluded a more disciplined process that would foster early attention to costs and better attention to option analysis, would lower costs for most projects and would better balance capital and production costs. Not surprisingly, it worked.

As a result of this experience, I believe capital and production costs without the use of this method can be as much as 5% above optimum. Since the largest chemical processing companies spent more than $100 billion of capital in 2007, this equates to as much $5 billion that could have been saved and invested elsewhere. Additionally, the non-optimum cost of products (or production costs) amounts to as much as $60 billion each year. These two stag-

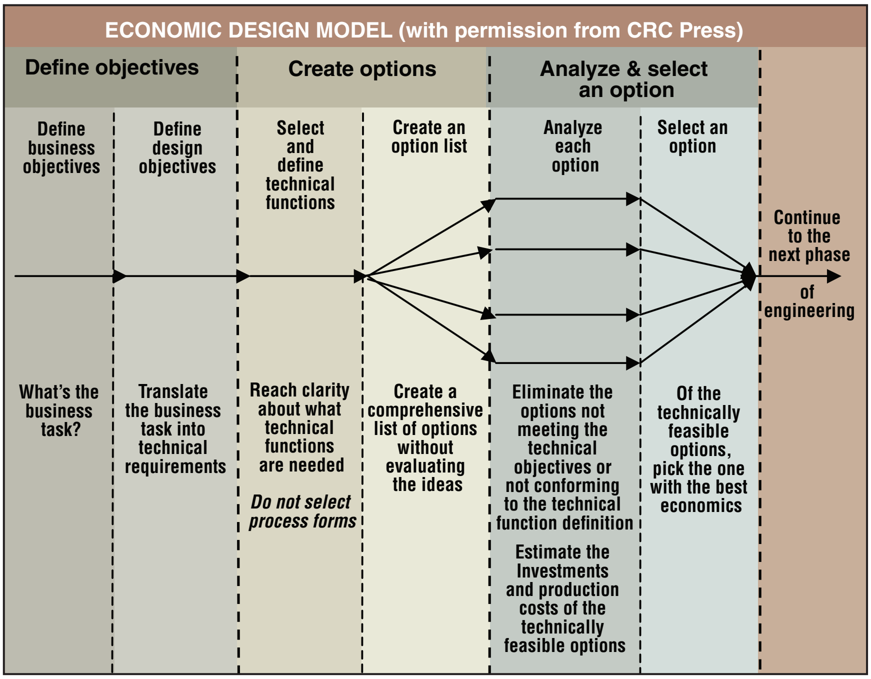


FIGURE 1. This model enables engineers to reduce capital and production costs by adjusting their decision making process

TABLE 1. CAPITAL AND COST OF PRODUCTION SPENDING FOR THE LARGER CHEMICAL RELATED COMPANIES, 2007[1]
(All amounts are in millions)

Industry / Company	Revenues	Capital	% of Sales	Cost of Production	% of Sales
Chemicals					
Dow Chemical	53,513	2,075	3.9	46,400	86.7
DuPont	29,378	1,585	5.4	21,565	73.4
3M Co.	24,462	1,422	5.8	12,735	52.1
PPG Industries	11,206	353	3.2	7,087	63.2
Air Products	10,038	1,055	10.5	7,362	73.3
Huntsman Corp.	9,651	665	6.9	8,111	84.0
Monsanto	8,563	509	5.9	4,277	49.9
Eastman Chemical Co.	6,830	518	7.6	5,638	82.5
Praxair	9,402	1,376	14.6	5,557	59.1
Rohm & Haas	8,897	417	4.7	6,430	72.3
Sherwin-Williams	8,005	166	2.1	4,407	55.1
Ashland	7,785	154	2.0	6,447	82.8
Celanese	6,444	288	4.5	4,999	77.6
Avery Dennison	6,308	191	3.0	4,585	72.7
Hexion Specialty Chemicals	5,810	122	2.1	4,994	86.0
Mosaic	5,774	292	5.1	4,848	84.0
Ecolab	5,470	307	5.6	2,692	49.2
Subtotals/Averages	217,536	11,495	5.3	158,134	72.7
Food Products					
Archer Daniels Midland	44,018	1,198	2.7	40,781	92.6
Kraft Foods	37,241	1,241	3.3	24,651	66.2
General Mills	12,442	460	3.7	7,955	63.9
Sara Lee	12,278	529	4.3	7,552	61.5
Conagra Foods	12,028	425	3.5	8,890	73.9
Dean Foods	11,822	241	2.0	9,084	76.8
Kellogg Co.	11,776	472	4.0	6,897	58.6
Heinz	9,002	245	2.7	5,609	62.3
Land O'Lakes	8,924	91	1.0	8,158	91.4
Campbell Soup	7,867	334	4.2	4,571	58.1
Hormel Foods	6,193	126	2.0	4,779	77.2
Wm. Wrigley Jr.	5,389	251	4.7	2,535	47.0
Hershey	4,947	190	3.8	3,315	67.0
Subtotals/Averages	183,927	5,803	3.2	134,777	73.3
Beverages					
Pepsico	39,474	2,430	6.2	18,038	45.7
Coca-Cola	28,857	1,648	5.7	10,406	36.1
Anheuser-Busch	18,989	870	4.6	10,836	57.1
Molson Coors Brewing	8,320	428	5.1	3,703	44.5
Subtotals/Averages	95,640	5,376	5.6	42,983	44.9

1. Taken from each company's 2007, Form 10-K

(Continues on p. 28)

gering amounts dimensionalize what might be saved by adjusting the way decisions are made during the various development stages leading up to and including plant design.

The disciplined method described in this article enables engineers to tap into this potential. The three key features of the method are as follows:

1. To find the best option, one needs to diverge early in a project, to consider multiple options before converging to a decision. This requires creating an option list more comprehensive and thorough than is typical.
2. When there is more than one workable technical option (which my experience says is very often the case), one should use economics to select the best of these options.
3. Economic decisions are best made on the basis of balancing capital and production costs, which means deciding if it is better to spend more capital and have lower production costs, or if it is better to spend less capital and have higher production costs.

During a project, the last item is considered again and again as options are explored. The decision requires finding out whether or not it is justifiable to spend capital to reduce production costs. To be justifiable, an option must have a return on investment (ROI) that equals or exceeds the company's hurdle rate. This is the basis of economic design. Note that balancing does not use lowest capital cost, lowest production cost, highest rate of return or other economic measures as decision-making criteria.

THE COST OF PRODUCTS

Included in product costs are the following components:

Raw materials: In-freight; product ingredients; catalyst and solvents; byproduct credits

Packaging materials: In-freight; product packaging (such as drums, bags, pails, plastic bottles, fiber cartons and corrugated containers)

Manufacturing: Operating labor (wages); utilities; employee benefits; supervision (wages and benefits); laboratory; maintenance; insurance and taxes; operating (consumable) supplies; plant overhead; depreciation; and contract manufacturing

Product delivery: Shipping costs ❑

THE ECONOMIC DESIGN

The Economic Design method enables engineers to reduce capital and production costs by adjusting their decision making process. The model (Figure 1) has three phases: setting project objectives; creating a thorough and comprehensive list of options; and doing a complete economic analysis of the technically workable options. Features unique to the Economic Design method include the following:

- Phases are integrated into a complete decision making and project management process.
- The method is ideal for decision making in the very early stages of a project, including product and process development, feasibility and conceptual phases. Large amounts of money are at stake in these phases because the decisions made set the future economic framework.
- Significant attention is paid to the creation of a list — more thorough than is typical — of design options. The lower-cost, more economic designs flow directly from the thoroughness and quality of the option list.
- Analyses and comparisons of options use after-tax cash flows to calculate either net present value (NPV) or after-tax annual cost (AC). These calculations use a company's hurdle rate as the discount rate.

TABLE 1. (Continued from p.XX) CAPITAL AND COST OF PRODUCTION SPENDING FOR THE LARGER CHEMICAL RELATED COMPANIES, 2007[1] (All amounts are in millions)					
Industry / Company	Revenues	Capital	% of Sales	Cost of Production	% of Sales
Household/Personal Products					
Procter & Gamble	76,476	2,945	3.9	36,686	48.0
Kimberly-Clark	18,266	989	5.4	4,388	24.0
Colgate-Palmolive	13,790	583	4.2	11,397	82.6
Avon Products	9,845	279	2.8	3,941	40.0
Estee Lauder	7,038	312	4.4	1,775	25.2
Clorox	4,847	147	3.0	2,756	56.9
Subtotals/Averages	130,262	5,255	4.0	60,943	46.8
International Paper	21,890	1,288	5.9	16,060	73.4
Weyerhaeuser	13,949	680	4.9	11,375	81.5
Subtotals/Averages	35,839	1,968	5.5	27,435	76.6
Petroleum Refining					
Exxon Mobil Corp.	390,328	15,387	3.9	231,383	59.3
Chevron Corp.	214,091	16,678	7.8	150,241	70.2
Conoco Phillips	187,437	11,791	6.3	125,112	66.7
Valero Energy	95,377	2,260	2.4	81,645	85.6
Marathon Oil	62,800	4,466	7.1	49,104	78.2
Sunoco	44,470	1,179	2.7	39,971	89.9
Hess	31,647	3,578	11.3	22,573	71.3
Tesoro	21,915	747	3.4	20,308	92.7
Murphy Oil	18,424	1,949	10.6	16,195	87.9
Western Refining	7,305	277	3.8	6,376	87.3
Frontier Oil	5,189	291	5.6	4,340	83.6
Subtotals/Averages	1,078,983	58,603	5.4	747,248	69.3
Pharmaceuticals					
Johnson & Johnson	61,095	2,942	4.8	17,751	29.1
Pfizer	48,418	1,880	3.9	11,239	23.2
Abbott Laboratories	25,914	1,656	6.4	11,422	44.1
Merck & Co.	24,198	1,011	4.2	6,141	25.4
Wyeth	22,400	1,391	6.2	6,314	28.2
Bristol-Myers Squibb	19,348	843	4.4	6,128	31.7
Amgen	14,771	1,267	8.6	2,548	17.3
Eli Lilly	18,634	1,082	5.8	4,249	22.8
Schering-Plough	12,690	618	4.9	4,405	34.7
Subtotals/Averages	247,468	12,690	5.1	70,197	28.4
TOTALS/AVERAGES	**1,989,655**	**101,190**	**5.1**	**1,241,717**	**62.4**

1. Taken from each company's 2007, Form 10-K

Project objectives

Objective setting is included in the Economic Design model because engineering work too often begins before the purpose of the project is really clear. The lack of clarity typically stems from situations such as the following: the engineers don't get input from the business managers, which results in an unclear business rationale for the project; the project leader believes everything is clear when that is not the case; or the project team talks about its objectives but does not write them down, resulting in later confusion. When project objectives are not set well, problems occur as the objectives get sorted out via trial and error during project execution. These projects experience a series of design changes, which most often cause schedule delays and cost increases.

A project team needs objectives to ensure those involved in the project agree upon the purpose. Good objectives are (a) developed from the input of the key stakeholders — business and technical managers — and the project team, (b) written and distributed to each stakeholder, (c) realistic and measurable, and (d) updated as project conditions change. Updating usually occurs at the beginning of each project phase.

I suggest setting objectives in two steps by first setting business objectives and then translating them into technical objectives. Business objectives answer questions such as the following: What is the *business reason* for the project? Is it to introduce a new or improved product, to decrease costs, increase production capacity, and so on? What are the *capacity requirements* of the project? What production volume must the process be able to produce? Must it all be on stream at one time or can it be phased in over time? What *schedule needs* are there? When does the new product need to be available for sale, when does the test market need to begin, when do the cost savings need to start, and so on? What are the *economic needs* of the project? Is there a minimum acceptable rate of return, is there a capital spending limit, is there a production cost limit, and so on? Are there *other* requirements? These include whatever is appropriate for the project.

Once a project's technical leaders have worked with business management to set the business objectives, the technical leaders and their management translate these into technical objectives. The two sets of objectives need to be completely compatible. By their nature, the technical objectives will go into more detail than the business objectives and will include the following:

- ***Business needs:*** This usually restates the business reason and adds needed technical details.
- ***Capacity:*** This often restates the capacity requirements and adds technical details, such as spelling out the target operating efficiency of the plant or process.
- ***Schedule:*** This usually details intermediate schedule requirements as dictated by the business objectives, for example, when the pilot plant construction needs to be finished so that process development can proceed on schedule.
- ***Economics:*** This is a restatement of business objectives plus any added items important to the technical community. For example, if there were limits on research, development or engineering spending, they would be covered here.
- ***Technical factors:*** This section covers items, such as key sources of technical data (pilot plant reports); how ancillary and utility systems should be handled; health, safety and environmental considerations; and so forth.

Four examples of business and technical objectives for the process development and feasibility engineering phases of an oil hydrogenation project are given below (with permission from CRC Press). Note how the business and technical objectives differ from each other and how the objectives evolve from project phase to project phase. A detailed description of setting project objectives can be found in Chapter 7 of Ref. 1.

Example 1: Business objectives (process development phase).

- Business plan: There appears to be a market opportunity for an extension of our present product line of oils. Develop a process for the product (code named "Product X").
- Projected volume: At this stage, potential volume is very uncertain. Estimates range from 200 to 700 million lb/yr. We will need to do further consumer testing to more accurately estimate volume.
- Timing: Complete the development work so the national introduction of Product X can begin by late 2006. Product for consumer testing will be needed as defined by the consumer testing schedule.
- Economic factors: We expect we will have to sell Product X at the same price as our existing products. Therefore, finished product production costs cannot exceed $1.27/lb. Develop the process accordingly.

Example 2: Business objectives (feasibility engineering phase).

- Business plan: Determine the economic feasibility for Product X. Include the cost of test market facilities in the study. The feasibility response should include a preliminary project schedule starting with the end of feasibility through the start of national production. Assume a one year test market.
- Projected volume: National volume is estimated at 400 to 600 million lb/yr. Base the feasibility on a volume of 600 million lb/yr. Test market volume is estimated at 6 million lb/yr.
- Timing: Complete the study within three months. If the project is feasible, begin test market shipments within nine months. We wish to begin national shipments by late 2006.
- Economic factors: ROI of at least 15%; National production cost for the hydrogenated part of the product is not to exceed $0.292/lb; Finished product production cost is not to exceed $1.27/lb; Capital spending for national and test market facilities is not to exceed $6 million.
- Other: Follow the company's health, safety and environmental policy.

Example 3: Technical objectives (process development).

- Business need: Develop raw material specifications and a hydrogenation process (including catalyst selection) for the new oil product, Product X.
- Schedule: Pilot plant construction must be completed within six months. This should permit process development to be complete by January 2004, enabling a start of national production in late 2006. Sample product for consumer testing must be available by July 2003.
- Economic factors: The production cost of the hydrogenated oil cannot exceed $0.292/lb. The finished product production cost is not to exceed $1.27/lb.
- Technical factors: Product characteristics are given in a research report. The projected capacity (200–700 million lb/yr) would indicate a continuous process. However, you should work with the plant design engineers to determine whether a batch or continuous process will be best from an economic standpoint. This will probably involve deciding how many process locations are best. Plant operation will be 24 h/d, 7 d/wk and 50 wk/yr. The other two weeks will be used for maintenance shutdowns.
- Health, safety and environmental: All regulations and company policy will be followed. Since the hydrogenation catalyst will most likely contain heavy metals, your work must consider how to properly dispose of and reclaim the catalyst.

Example 4: Technical objectives (feasibility engineering).

- Business need: Develop a feasibility grade design and estimates for the test market and national manufacturing facilities needed to produce Product X. Assume volumes of 6 million lb/yr for test market and 600 million lb/yr for national production. Provide these data to the financial department so they can determine whether Product X is feasible. As a part of the study, develop a milestone schedule for the funding, design, construction and startup of the test market and national facilities. Assume a one-year test market. Assuming Product X meets the economic factors below and is economically feasible, you should also prepare appropriation requests to fund test market construction, national conceptual engineering and long-lead-time equipment purchase.
- Schedule: Complete the feasibility and appropriation requests within three months.
- Economic factors: The ROI must be at least 15%. Production cost for the hydrogenated oil is not to exceed $0.292/lb and for the finished product is not to exceed $1.27/lb. Capital spending, for test market and national production, cannot exceed $6 million.
- Technical factors: Product X contains a specially hydrogenated blend of 70/20/10 soybean/cottonseed/safflower oils. Operating conditions and the hydrogenation endpoint are specified in the pilot plant report. Operation will be 24 h/d, 7 d/wk and 50 wk/yr. The other two weeks will be used for maintenance shutdowns.
- Health, safety and environmental: All regulations and company policy will be followed. There are no health hazards. H_2 handling is the only special safety risk. Environmentally, spent A3 catalyst will be returned to the manufacturer for reclaiming. Ensure the fat settling traps have sufficient capacity to keep the amount of oil in the wastewater at levels treatable by the sewage treatment plant.

Creating a list of options

The heart of Economic Design is a thorough and comprehensive list of options. Without a list, finding the most economic technical option becomes a game of chance. Given the importance of the option list, it is surprising that option creation often falls short of the mark. I believe this occurs for several reasons. First, there are usually heavy schedule demands on engineers. A tight schedule makes the

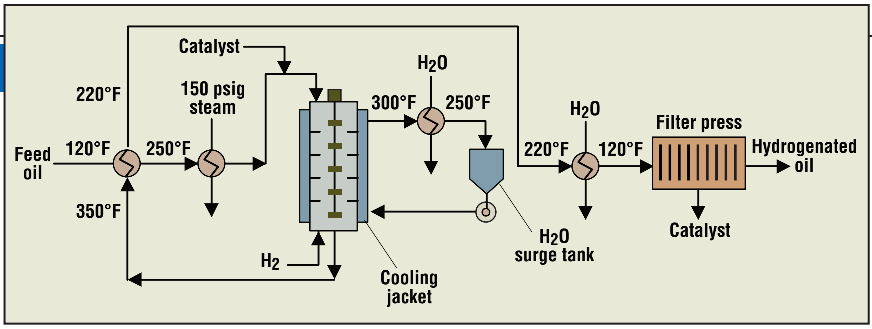


FIGURE 2. An engineer might develop a flowsheet like this one to satisfy the business and technical objectives given in Examples 1 and 3

study of options difficult, as it seems there is not enough time to do anything other than find some workable answer. While short schedules will at times be the correct path, decision makers need to weigh what that will cost in terms of increased capital and production costs. A second reason is that engineers have a desire to quickly develop answers for their designs. By their nature, engineers are good problem solvers who enjoy finding answers to design questions. This creates a tendency to converge to answers, at times faster than is appropriate.

Another reason options aren't considered is that many companies have standardized the design of their plants and processes. When that is the case, engineers are often reluctant to examine options that would change the standardized designs, even when improved technology is available or when economic conditions have changed. There may also be pressures from within the company not to change anything. And finally, option list creation is just plain hard to do.

Option-creation tools. Brainstorming and its variations are often used for generating options. There are three other easy-to-use tools that will help bridge the option creation gaps mentioned above. All bring discipline to the option creation process. Requiring minimal effort and time expenditure, these tools promote divergence before design answers are selected, promote higher levels of understanding of the design and help spark creativity.

The first tool is a bit different methodology for flowsheet development. It focuses on the technical purpose, or the technical function, of each step in the process rather than on specific unit operations. Once the technical functions are selected, the engineer analyzes the process and studies options. These actions culminate in a process flow diagram. The technical function method allows the engineer to consider options before selecting unit operations.

The second tool is a set of eight unit operation guides. These list most of the unit operations available for different technical functions, such as drying or reacting. Using the guides, an engineer can develop a list of unit operation options for the technical functions on a flowsheet within minutes. Without the guides, this would take most engineers days to complete.

The third tool is a set of questions intended to expand an engineer's understanding of the process. A few examples of questions are as follows: How do the upstream unit operations or processes affect the unit operation being considered? What different grades and sources of raw materials are available, and how do they affect the process? Should a product or raw material be bought or made? If it must be made, should a contract processor make it or should one's company make it? The premise behind these kinds of questions is that increased understanding will lead to improved designs and additional options.

Flowsheet development. The methodology used to develop flowsheets greatly affects thoroughness and completeness of an option list. Consider the following example.

When asked to design an oil hydrogenation process that will satisfy the business and technical objectives given in Examples 1 and 3 of the previous section, an experienced engineer might sketch the flowsheet shown in Figure 2. The process is workable and uses standard equipment. Given that, design work could proceed based on the flowsheet.

Reflect, however, upon what happens when an engineer uses Figure 2 as the starting flow diagram. As drawn, the flowsheet shows a continuous process; shell-and-tube heat exchangers for all the heat transfer operations; a multistage, stirred column reactor with a cooling jacket; a circulating water system to cool the reactor; preheating the feedstream with hot oil from the reactor; and catalyst removal via a plate-and-frame filter operating at 120°F.

While all these design choices are workable, picking them prior to the exploration of other alternatives eliminates many options from consideration, some of which are just as technically good and might be better economically. For example, the following would not have been considered: a batch process; plate-and-frame heat exchangers; static mixers; a continuous, well-mixed reactor or other configurations of a continuous stirred tank reactor (CSTR); coils inside the reactor for removing the heat of reaction using the feedstream (as opposed to recirculating water) as the reactor coolant; an enclosed vertical-tube filter, which would permit high temperature filtration (reducing filter size); or a disc centrifuge.

TABLE 2. TECHNICAL FUNCTIONS AND UNIT OPERATIONS

Technical Function	Type of Unit Operation
Separate solids from the oil	Pressure filter
Heat oil	Shell-and-tube heat exchanger
React oil with hydrogen	Vertical, multi-stage stirred column reactor

To counter this kind of premature convergence to design solutions, Economic Design starts the flowsheet creation process with block flow diagrams showing the technical functions in the process and not specific unit operations or equipment types. These block diagrams are called technical function flowsheets (TFFS). TFFS methodology helps to slow convergence to design specifics until there has been a thorough look at different options. Table 2 illustrates the difference between technical functions and unit operations.

Note that the technical function descriptions are verb-object combinations. For example, separate (the verb), solids (the object). Unit operation descriptions are nouns, often modified by an adjective. Additionally, technical function descriptions are less specific and more generalized than the unit

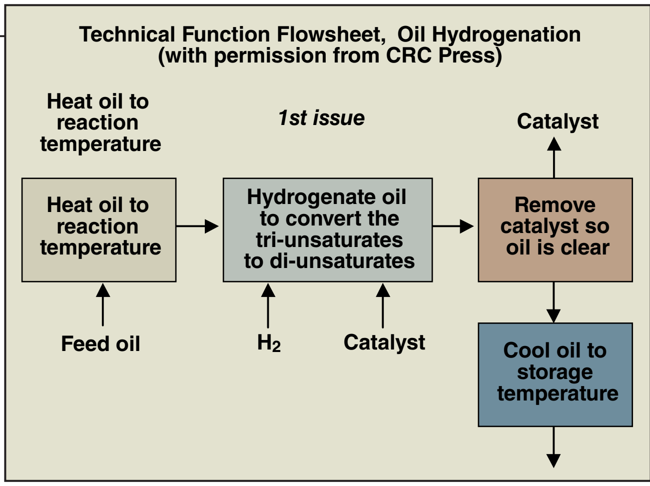


FIGURE 3. A first issue of a technical function flowsheet (TFFS) might look like this. Note how it differs from the flowsheet shown in Figure 2

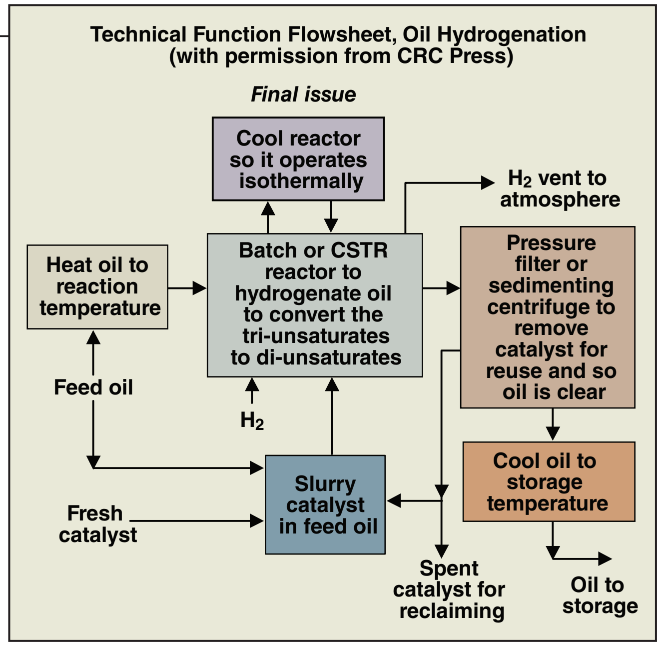


FIGURE 4. A final issue of the TFFS shows that the design issues have been resolved

operation descriptions, opening the opportunity for option creation and examination. TFFSs show each function in the process in its correct order and all major flowstreams, including the direction of their flow. Figures 3 and 4 are examples of TFFSs for oil hydrogenation. Contrast Figure 3, which shows what the first issue of a TFFS would look like, to Figure 2, noting the freedom the TFFS gives the engineer to identify and explore options.

Figure 4 is the final issue of the TFFS. Contrasting it to the first issue of the TFFS one notes that the engineer has answered many design questions, such as the venting of H_2 to the atmosphere and the reclaiming of spent catalyst; has narrowed reactor selection and catalyst removal to two choices each; and has left a number of items open, such as the type of heat transfer equipment to be used, the heat recovery scheme and the method of cooling the reactor. It is best to leave open as many items as possible until more detailed design begins. That way the engineer can make final choices based upon the most current technology and economics.

To keep track of and communicate a design, the engineer needs to document a lot more data than shown on the TFFS. Thus, the TFFS is backed up by material and energy balances (often based on pilot plant data) and a detailed table called a Technical Function Definition. This table, arranged by technical function, explains the purpose of each function, lists the important operating conditions (flow, temperature, pressure and so on) and describes the basis for the selection of operating conditions [2].

Unit Operation Guides. Use of the TFFS methodology sets the stage for option list creation. When it is time to select unit operations for the different technical functions, the Unit Operation Guides [*1*] will help an engineer to define most of the potential options. The guides list only the more common unit operations, so atypical operations may not be included. For example, the Mass Transfer Guide does not include reactive distillation, a less common operation. Eight guides are available covering the following topics: blending-mixing; drying (water removal only); heat transfer (including evaporation); mass transfer (including crystallization); material transport; mechanical separation; reactions; and size modification. Each is subdivided by the phases that are transformed by the technical function. For example, the Blending-Mixing Guide has five phase subdivisions: gas-liquid, liquid-solid, gas-gas, liquid-liquid and solid-solid. Having defined a technical function, which would include knowing the phases involved, one can simply go to the appropriate guide and find a list of the unit operations that should be considered. The guides also include the references used to compile the lists and some additional pertinent comments.

To better illustrate the use of guides, we will use the Reaction Guide — one of the more complex guides — as an example. Let us say that the assignment is to develop a list of possible unit operations for the technical function shown in Figure 3, "hydrogenate oil to convert the tri-unsaturates to di-unsaturates". Additional data include the reaction temperature, pressure, hydrogen usage and the fact that a finely divided nickel catalyst is used at a specific concentration in the feed oil. Since the technical function in question is a reaction, the Reaction Guide would be located. This guide has six different phase options including gas-liquid, liquid-solid, gas-solid, liquid-liquid or one liquid, solid-solid or one solid, and gas-gas or one gas reactant [*3*].

Since our example is a catalyzed gas-liquid reaction, we would go to the gas-liquid column in the guide (shown in the box titled "Options for the hydrogenation reactor"). A caution, do not yet start evaluating the options; save this for the option analysis phase of the Economic Design model. If evaluation and idea generation are done concurrently, the evaluating will stifle idea generation; and the quality of the option list will suffer. Without the guides, developing an option list like this would be very time consuming and would probably not be as complete. In fact, seldom are lists this complete to be found. In the next model phase, one evaluates each option, first technically, then economically.

A list this long just for the reactor might seem daunting, but the first-cut technical analysis usually goes rather quickly and eliminates many of the options. Remember, the goal is to create a comprehensive list, one that includes options that wouldn't necessarily get on most lists. This is the root of truly creative and new ideas, some of which will produce better-than-typical results and profits.

Question lists. Intended to increase the depth of understanding about a process, a series of questions will lead to the creation of more options and higher quality designs. There are three sets of questions given in Ref. 1: general process, process interactions and feasibility/conceptual. The first two are more general in nature than the feasibility/conceptual questions. As such, they would be used more often during process development or early in plant or process design.

The general process and process interaction questions address broad project issues, such as the following examples: Should a product or intermediate be bought or made? Should the process be batch or continuous? What grade and purity of a raw material should be purchased? Should recycle or purge streams be used, and do those streams need to be treated before reuse or disposal? How does this unit operation affect the downstream operations?

I have repeatedly found that questions like these, ones that lay the foundation for a project, are not addressed well because the answer seems obvious, and there does not seem to be enough time to answer them, or because no one thought to ask the questions. I have also seen them addressed late in a project, in which case the answer may well dictate a fundamental change in direction that is usually painful to implement. When this happens, the questions are sometimes answered superficially so as to not upset the project. I have also seen attempts to suppress an answer when the pain of change was very great. Thus, there is a need to thoroughly deal with the questions early in the project.

Let us consider the "make or buy" option in a bit more detail. If the product or intermediate is something a supplier can deliver to your plant for less money than you can make it, the choice is simply to buy it. When, however, you can make it for less than you can buy it, the answer is not so simple. If the product has a high market risk, buying the material until the market is proven might make more sense. That way, if the market fails, there is no capital to be written off. When the market is successful, you can build whatever facilities are needed to produce the material internally. If your company has cash flow restrictions, the cash flow from buying the material is less than the cash flow from capital procurement and construction. Buying might also make sense if it allows your company to get into the market place faster. Your own plant can be built later. This also has the advantage of lowering the market risk. Additionally, you might make part and buy part. That lets you fully load your facility and use the supplier for production swings.

Since we are considering questions to ask while engineering is still in its early stages, the feasibility and conceptual questions will be broad, but are focused on the design of the plant. Some of the questions from the general process list, such as make versus buy and batch versus continuous, may still need to be dealt with. Examples of additional questions include the following: How many sites are economically optimum and where should they be located? Are there materials used or made in the process that are hazardous from a health, safety or environmental standpoint or that need environmental treatment? If so, can they be eliminated, be used in reduced quantities, or be replaced by less hazardous or non-hazardous materials?

Economically optimum siting is worth some added discussion. Deciding on the number of sites involves the balancing of capital and production costs. Because of economies of scale, having more sites usually results in higher capital, startup and manufacturing costs. When plants are sited based on supplier and customer locations, having more sites decreases in-freight and product shipping costs, because the plants are closer to the suppliers and customers.

OPTIONS FOR THE HYDROGENATION REACTOR

This list is taken from the gas-liquid column of the Reaction Guide [*1, 3*]. It gives the engineer an easy-to-find resource for options to consider for the process design.

- Batch reactor
- Static mixer
- Shell-and-tube heat exchanger, tube side
- Packed column
- Tray tower
- Spray tower
- Venturi mixer
- Pump impeller

- Fixed catalyst bed
- Trickle catalyst bed
- Ebulating catalyst bed
- Rising-film reactor
- Falling-film reactor
- Continuous well-mixed reactor
- Membrane reactor

- Continuous stirred tank reactors (CSTR)
  - Tanks in series
  - Vertical, multi-stage agitated vessel
  - Horizontal, compartmented, agitated vessel

TABLE 3. ECONOMIC VARIABLES ANALYSIS

Cost Variables	Does the Variable Change?	Comments
Investments		
Capital	Yes	Varies dependent insulation thickness
Working capital	No	Ignore
Startup expense	No	Ignore
Supplier advances/ royalties	No	Ignore
Production costs		
Raw materials	No	Ignore
Packaging materials	No	Ignore
Product delivery	No	Ignore
Manufacturing, including the following costs:		
Operating labor	No	Ignore
Employee benefits	No	Ignore
Supervision	No	Ignore
Laboratory	No	Ignore
Utilities	Yes	Varies dependent upon the energy loss through the insulation
Maintenance	Yes	Varies as a function of the capital
Insurance and taxes	Yes	Varies as a function of the capital
Operating supplies	No	Ignore
Plant overhead	No	Ignore
Depreciation	Yes	Capital/Insulation life

COST VARIABLE CHECKLIST

Use the following checklist to ensure that all dependent economic variables are considered.

Investments. Capital; working capital; startup expenses; supplier advances and royalties

Production costs. Raw materials; packaging materials; manufacturing (including operating labor, employee benefits, supervision, laboratory, utilities, maintenance, insurance and taxes, operating supplies, plant overhead, depreciation); product delivery

(With Permission from CRC Press)

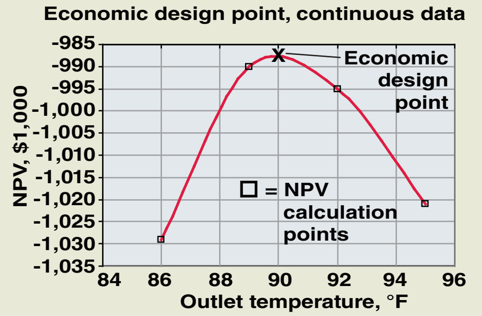


FIGURE 5. When many technical options are available, a plot helps to pinpoint the economic optimum

Analyzing and selecting

Once a list of options exists, one enters the analysis and selection stage of the Economic Design model. This is a two-phase process with technical analysis followed by economic analysis.

Technical analysis. In technical analysis, one examines each option to determine whether or not it can meet the technical needs of the process. These needs are defined by the project objectives, quality and operating efficiency specifications, capacity requirements and so on. Any option that cannot meet the technical needs is eliminated. Remaining options are then analyzed for best economics. Engineers employ many different ways to make their technical assessments. For example, they may use plant operating data; results from bench-scale tests, pilot plants, semi-works plants, or full-scale plants; other company experience; the experience of a process expert; and process design and unit operation books or articles.

Economic analysis. Usually there's more than one item left on the option list after technical analysis. When that is the case, one uses economic analysis. This is a five-step process. First, select the independent and dependent variables for the economic study. Second, pick the initial values for the independent variable. If these values do not locate the economic optimum, recycle and select another set of values. Third, for each value of the independent variables, roughly size and select the equipment involved, and estimate the capital cost of the equipment, any other investments and the production costs. Fourth, convert the cost data from step three into after-tax (AT) cash flows, and calculate the net present value (NPV) or the annual cost (AC) for each value of the independent variable. Fifth, select the value having the largest NPV or AC. That is the best option, the economic design point.

In the third step of rough equipment design, and investment and production cost estimating, one only needs to estimate the costs that will be different as the values of the independent variable change. The checklist in the box titled "Cost variable checklist" will help ensure one considers all the dependent economic variables.

As an example, if one were trying to find the economic thickness of insulation for 3-in. pipe, the independent variable would be insulation thickness and one would select the different thicknesses to be examined. For each thickness (each value of the independent variable), one would also calculate the energy loss. Using the checklist in the box, the engineer decides which costs will change as the values of the independent variable vary. This is summarized in Table 3.

Thus, for each insulation thickness, one estimates capital, utility, maintenance, insurance and taxes and depreciation costs. In the fourth step, these costs are used to calculate either NPV or AC for each thickness. In the fifth and last step, the thickness having the highest NPV or AC is selected. This is the option having the best economics and is therefore, the economic design point.

Calculation methods. A few comments are in order about calculation methodology.

When estimating costs (the 3rd step mentioned in the previous section), during option analysis early in a project, there are not many details available. Study-grade-estimating methods (Chapters 3 and 4 in Ref. 1) are designed to create reasonably accurate estimates when little design data are available. More detailed design and estimating techniques are just not needed when analyzing most options.

When calculating NPV or AC (the 4th step mentioned earlier), I espouse using after-tax cash flows, because this bases the calculations on the money that actually flows out of and into a company's bank account. Using NPV or AC makes sense as both permit the easy comparison of multiple options, because they can take into account uneven cash flows and because they can be calculated using a company's hurdle rate.

The 5th step outlined above mentions the economic design point. This is simply the option having the highest NPV or AC. Quite often, these values at the economic design point will be negative, because most of the cash flows that are different from option to option are costs, and thus negative. When there are a discrete number of options, such as in the example of the insulation thickness, the economic design point is the insulation thickness having the highest NPV or AC. When there are an infinite number of options, such as picking the most economic outlet temperature in a heat-recovery heat exchanger, one should plot NPV or AC versus the independent variable to locate the optimum. This is illustrated in Figure 5. ■

Edited by Dorothy Lozowski

References

1. Brown, Thane, "Engineering Economics and Economic Design for Process Engineers", CRC Press, 2006.
2. A table showing the technical function definitions corresponding to the TFFS in Figure 4 can be found by searching the title of this article on www.che.com
3. The full Reaction Unit Operation Guide can be found by searching the title of this article on www.che.com

Author

Thane Brown is presently chairman of the Advisory Committee for the Chemical Engineering Dept. at the University of Dayton (Email: trbnjb@earthlink.net). He has taught plant design and engineering economics at the Universities of Dayton and Cincinnati as an adjunct professor. Prior to teaching, Brown worked for Procter & Gamble for over 36 years in a variety of engineering and manufacturing roles primarily in the food-and-beverage business and in health, safety and environmental engineering. His last position there was director, North American Engineering. Brown has recently published a book on engineering economics and design [*1*], and has written a number of articles on engineering economics, batch pressure filtration and heat transfer. He is a registered professional engineer of Ohio and holds a B.S.Ch.E. from Oregon State University.

Wastewater Treatment: Energy-Conservation Opportunities

Abtin Ataei
Graduate School of the Environment and Energy, Science and Research Branch of I.A.U.

Consider these options to improve energy efficiency and reduce the cost of treating wastewater

Typical wastewater-treatment plants (WWTP) — both industrial and municipal — consume large amounts of energy, which can represent 50% or more of the facility's variable operating and maintenance costs. Most employ biological processes that rely on energy-intensive aeration systems whose energy consumption is approximately 0.5 kWh per m^3 of effluent treated. This article discusses a variety of design and operating improvements that can be undertaken to reduce energy consumption (and related costs) during wastewater treatment. Case study results from representative WWTP scenarios are presented throughout the discussion.

The specific energy-conservation options presented here are organized into five specific proposals, each of which is discussed in detail below:

- Optimize aeration and oxygen transfer
- Use variable frequency drives (VFDs) to adjust the speed of electric motors to meet process demand
- Replace old electric motors with more-energy-efficient ones
- Maximize the production and use of biogas as a fuel
- Design an efficient, distributed effluent cooling system

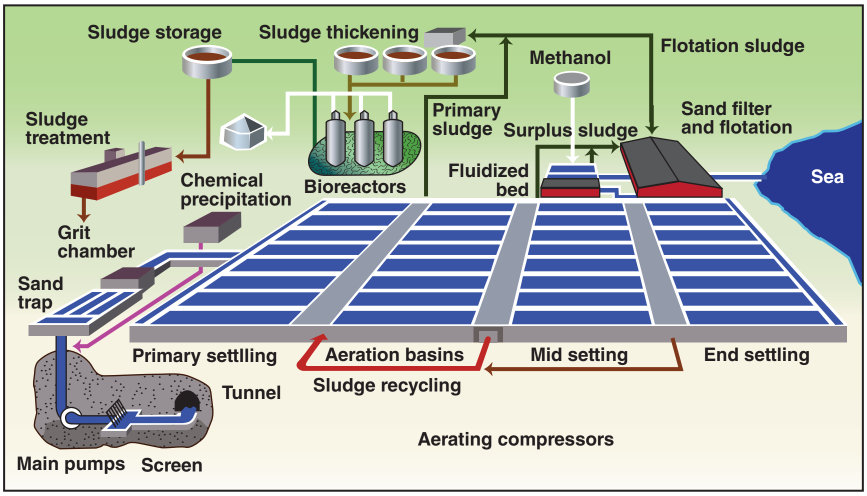


FIGURE 1. The main components of the reference WWTP used to develop the case examples provided in this article are shown here

Typical system components

The biological treatment of wastewater is carried out by microorganisms, mainly bacteria, which degrade the organic matter under either aerobic or anaerobic conditions [*1*]. The degraded matter is then bound into flock particles and separated as sludge.

Under anaerobic conditions, biological degradation is carried out in the absence of oxygen, so the microorganisms use nitrate as the oxidizing agent. The organic substances are oxidized into carbon dioxide and water, while some part of the matter is degraded into methane gas [*2*].

Under aerobic conditions — the more commonly used approach for wastewater treatment — oxygen must be supplied to support the biological processes. Here again, the organic material is oxidized into mainly carbon dioxide and water, and some part of the organic material is used to support bacterial growth.

Anaerobic biological treatment is usually performed using either a fixed-film process or activated-sludge process [*2*].

The fixed-film biological treatment process. These systems let the wastewater pass through a substrate, while the entire treatment stream is oxygenated. The culture of microorganisms that grows on the substrate consumes the organic matter in the wastewater. As the layer of microorganisms grows thicker, it periodicaly sloughs off and ends up in the wastewater effluent stream. The microorganisms are separated as sludge in an adjacent settling basin [*2*].

The activated-sludge treatment process. By comparison, biological treatment systems that use the activated-sludge process keep the sludge (which contains the microorganisms) suspended in the basin, and rely on some type of aeration device to deliver air or oxygen to the wastewater, in order to support the metabolic processes of the aerobic microorganisms. To achieve an adequate rate of organics degradation, a portion of the sludge is continuously recycled and a small amount of sludge is periodically removed [*2*].

The aeration process. During both fixed-film and activated-sludge processes, the organisms feed on organic substances, reducing the amount of organics in the wastewater. Additionally, bacteria transform ammonium, originating from urine, into nitrate. Such nitrification is a vital part of ongoing purification.

Air is often supplied using indi-

NOMENCLATURE

$a_{1,2,3}$, $b_{1,2,3}$, $c_{1,2,3}$	Mass transfer coefficient constants
A_{cr}	Cross-sectional area, m^2
A_{fan}	Fan casing area, m^2
A_{fr}	Tower frontal area, m^2
A_i	Heat and mass transfer area, m^2
A_{ic}	Area-independent initial cost, $
ACS	Annual cost savings, $/yr
AES	Annual energy savings, kWh/yr
C	Unit conversion factor, kw/hp
C_{elec}	Electricity cost, $/kWh
C_i	Initial cost of tower per unit volume, $/$m^3$
C_p	Specific heat of water at constant pressure, kJ/kg°C
E_f	Economic factor
E_{ee}	Efficiency of energy-efficient motors, %
E_{std}	Efficiency of standard motors, %
h	Enthalpy, kJ/kg
h_a	Heat transfer coefficient of air, $kW/m^2°C$
h_d	heat transfer coefficient of water, $kW/m^2°C$
HPS	Motor horsepower rating, hp
hrs	Annual operating hours, h/yr
IC	Initial cost, $
LF	Load factor as decimal
K_a	Tower characteristic, kg/m^3 s
K_{el}	Eliminator coefficient
m	Flowrate, kg/s
M_{air}	Average molecular weight of air, kg/kmol
n	Adiabatic factor
P	Power, kW
P_{in}	Pressure of inlet air to the compressor, atm
P_{out}	Pressure of outlet air to the compressor, atm
Q	Heat transfer rate, kW
R	Gas constant, kJ/kmol K
Ry	Eliminator characteristic, m^{-1}
SP	Simple payback time, yr
T	Temperature, °C
TC	Total cost, $/yr
Ur	Utility rate, $/kWh
W	Cooling tower width, m
Z	Cooling tower height, m

Greek letters

η	Efficiency
ρ	Density, kg/m^3

Subscripts

a	Air
c	Compressor
fan	Fan
in	Inlet
out	Outlet
opt	Optimum
w	Water
i	Interface

vidually controllable, high-capacity compressors, which produces an airflow that corresponds to the amount of biological oxygen demand (BOD) in the inlet stream. Aeration systems (discussed below) also provide mixing, which helps to keep solids suspended.

Adjusting key variables

Another variable that can be optimized to reduce energy use is the solids-retention time (SRT) of the activated-sludge process. The ability to maintain a high or low SRT typically has a corresponding effect on both the amount of excess sludge that must be wasted from the process, and the overall energy requirement for aeration.

For instance, if a facility is not required to nitrify the stream, and sludge-disposal costs are not high, then reducing the SRT may provide a cost-effective way to lower the total volume of suspended solids in the mixed liquor or reduce the number of aeration tanks in service.

However, to meet their discharge limits, many facilities are required to meet limitations on ammonia nitrogen in the effluent, and thus must operate their aeration systems carefully to ensure that a certain level of nitrification occurs. Unfortunately, nitrification often raises oxygen demand substantially.

One way to reduce energy use for facilities that must nitrify their wastewater stream is to create an anoxic (oxygen-deficient) zone at the head end (inlet) of the aeration basin. This approach is best applied at plants using the activated-sludge process. First, an anoxic zone zone is created — typically involving 15% of the total aeration tank volume — by reducing the air flow significantly in that part of the process [*3*]. This allows the bacteria to use the nitrate to oxidize waste BOD.

Aeration equipment. As noted, the equipment used to deliver oxygen to the aeration system is typically provided by surface aerators (such as low-speed mechanical aerators, direct-drive surface aerators, and brush-type surface aerators [*3*]), or by diffused aeration systems (such as low-pressure, high-volume compressors or blowers, air piping systems, and diffusers that break the air into bubbles as it is dispersed through the tank). Positive-displacement, and single- and multi-stage centrifugal blowers are commonly used.

Some aeration equipment combines diffusers with mechanical aerators. Submerged turbine aerators use sparger rings to deliver diffused air beneath mechanical mixers. As the bubbles rise, the mixers shear the coarse bubbles and provide mixing, too. Many diffuser styles are available.

The value relating oxygen saturation in wastewater to that of clean water is the beta value (ß). Generally, for wastewater effluent, a beta value of 0.95 to 1.0 is considered ideal.

While many facilities opt for fine-bubble, diffused-aeration systems to improve system efficiency, the blowers used by these systems are often oversized to guarantee a margin of operating capacity. They often end up being operated at less than 50% of their designed capacity, using variable-speed drives (VSDs) or throttling valves to control air flows in order to maintain a target dissolved-oxygen level on the order of 4 to 5 mg/L (the ideal range is closer to 1.5 to 2.0 mg/L).

In this case, inefficiency results from both operating an aeration system at excessively high dissolved oxygen levels, and from the poor mechanical efficiency that results when blowers are constantly throttled to operate at reduced outputs.

A comparison of guaranteed shaft horsepower (hp) values from competing blower manufacturers, at specified humidity, temperature, and turndown air flows, reveals some surprising results. For instance, while some facilities may feel that the use of a positive-displacement blower with a VSD will provide an efficient system at reduced air flows, the energy use required for such a setup is much higher compared to an alternate approach that uses an efficient, single-stage centrifugal blower controlled with damper controls. In fact, the latter approach can provide impressive savings.

Efforts to compare the guaranteed shaft-brake horsepower values of competing manufacturers are challenging. The most accurate method is the ASME Power Test Code PTC-9 for positive-displacement blowers, and the ASME PTC-10 for centrifugal blowers.

When individual aeration systems are reviewed for energy-saving opportunities, operators often overlook the fact that, in addition to providing aeration, this equipment provides mixing to keep solids in suspension.

Some facilities have successfully used a combination of high-efficiency mixers (for instance, those rated at 0.23 hp/1,000 ft^3 or more), in conjunction with aeration equipment, to optimize their overall aeration process. In this scenario, the mixers can be used during periods when mixing energy requirements are highest, in order to

TABLE 1. A COMPARISON OF ENERGY INTENSITY FOR THREE MAIN AERATION TECHNOLOGIES			
Parameters	Coarse-bubble diffusers	Micro diffusers	Surface aeration
Specific rate, kg O_2/kWh	1	2	Not applicable
kWh/d	5,500	2,750	

TABLE 2. CAPITAL AND O&M COSTS OF NEW EQUIPMENT REQUIRED FOR PROPOSAL 1		
Item	Capital cost, $	Annual cost, $
Compressing system	100,000	6,400
Compressed air tank	250,000	16,000
O&M annual cost		10,000
Total annual cost		32,400

maximize treatment efficiency while minimizing overall energy demand.

The activated-sludge process. Activated-sludge systems involve very complex biological processes [*4, 5, 6*]. More than 80% of the energy is consumed in the biological aerated reactor (BAR). Oxygen demand within a BAR can be met in various ways, but most aeration devices currently being used in activated-sludge processes may be classified as *diffused*, *dispersed*, or *surface aeration systems*.

The process produces effluents with relatively low levels of carbonaceous organics (characterized as BOD) and suspended solids. At the same time, however, the excess sludge that is produced might yield biogas ($CH_4 + CO_2$) during anaerobic digestion. As discussed below (in Proposal 4), this biogas may be used to heat the digester, to produce steam, to produce electricity, or to run direct-drive equipment. This is one big advantage of using anaerobic digestion.

By contrast, aerobic digestion processes do not produce sufficient quantities of biogas to offset fuel or electricity needs meaningfully.

In many regions, electricity costs are structured in such a way that usage during peak hours incurs rates that are many times higher than rates incurred during off-peak periods. This creates a strong incentive for operators to devise ways in which power consumption from the grid can be maximized during off-peak periods and minimized during peak periods.

Such efforts include attempts to optimize the selection and use of energy-intensive aeration devices, process flow configurations, and biogas utilization, to enable maximum operation during off-peak hours.

To evaluate potential opportunities for reducing energy costs in this way, a sample biological WWTP will be used as a case study throughout the balance of this article (Figure 1).

General data for this facility are:

- Flow equals 10,000 m^3/d
- BOD in is 600 mg/L
- BOD out is 50 mg/L
- BOD removed is 5,500 kg/d

These assumptions were used:

- 1 kg BOD removed requires 1 kg of O_2 transferred in the biological treatment process
- 8 h/d of off-peak electricity required
- Electricity costs are: peak at $0.08/kWh; off-peak at $0.02/kWh
- Aeration rates are uniform throughout the day (24 hours)
- The process configuration is extended aeration
- Investments are spread over 20 years, at 5% annual interest rate

PROPOSAL 1. OPTIMIZE AERATION AND OXYGEN TRANSFER

Today,'s most widely used aeration technologies are listed here [7]:

Surface aeration uses brush aeration, horizontal rotation or vertical rotation to force air into the liquid by the generation of violent turbulence at the surface.

Submerged air diffusion uses coarse-bubble systems or micro-diffusers to compress air and transfer it via pipes to a distribution system installed along the bottom of the basin.

Experience shows that in most cases, horizontal surface aerators are capable of transferring between 1.4 to 1.45 kg O_2 per 1 kWh, while aeration systems that rely on brushes are typically able to maintain a ratio of roughly 1.6 to 1.7 kg O_2 per 1 kWh [7].

In general, air diffusion systems may be characterized as *coarse (large) bubble systems*, which diffuse air through rather large holes in a distribution pipe, or *micro-diffuser systems*, which produce finer bubbles. Coarse-bubble systems provide relatively low oxygen transfer rates (on the order of 1 kg O_2 per 1 kWh). By comparison, the newer micro-diffuser technology produces smaller bubbles, whose larger surface area increases the rate of oxygen transfer to 2–3 kg O_2/kWh.

Peak versus off-peak air compression

To assess the potential impact of maximizing air compression during off-peak hours (to capitalize on lower electricity costs), follow these steps:

- Use the most efficient aeration technology (micro-diffusers) whenever possible
- Compress air during off peak hours and use it during peak hours
- Evaluate the new energy cost
- Calculate any added investment and operations and maintenance costs required to make the upgrades

Use most efficient aeration technology. The advantages of micro-diffusers are shown in Table 1, which compares the energy intensities of the two main aeration technologies (coarse-bubble versus micro-diffusers).

Compress air during off-peak hours and use it later. To assess the overall energy cost, the compression energy must first be calculated. During off- peak hours, the two aspects of compressed air production discussed next must be evaluated.

First, determine the amount of aeration that is required for the normal operation of the plant. To do this, calculate the energy use of continuous micro-diffuser air supply during 8 hours of off-peak time using the following expression:

$$\frac{2{,}750\text{kWh/d}}{24\text{h/d}} \times 8\text{off-peakh/d}$$
$$\approx 917\text{kWh/d}$$

Next, calculate the amount of air required for compression to maintain desired aeration levels during peak hours. To do this, calculate the energy use required for these 16 h/d (assumed peak-hours operation) , as follows:

$$5{,}500(\text{kgO}_2/\text{d}) \times \left(\frac{16}{24}\right) = 3{,}667\left(\frac{\text{kgO}_2}{\text{d}}\right)$$

For micro-diffusers, the common efficiency ratio of kg air per kg O_2 is taken as 6.7 [7], thus giving a total air amount of 24,570 kg air. This is the amount of air that needs to be compressed during 8 off-peak hours.

Using Equation (1) [*3*], the electricity required to produce the above amount is 250 kW.

TABLE 3. COMPARISON BETWEEN STANDARD-EFFICIENCY (SE) MOTORS AND ENERGY EFFICIENT (EE) MOTORS [9]

Motor (hp)	Purchase cost, $			Efficiency, %		Annual savings		Simple pay-back time
	SE	EE	Difference	SE	EE	kWh	$	Years
10[a]	614	795	181	86.5	91.6	2,103	210	0.86
25[a]	1,230	1,608	378	88.1	94.2	6,004	600	0.63
50[a]	2,487	3,207	720	90.6	95	9,352	835	0.86
100[a]	5,756	7,140	1,384	90.7	95.7	18,822	1,882	0.74
200[b]	11,572	13,369	1,797	94.6	96.1	10,782	1,078	1.67
300[b]	15,126	18,385	3,259	94.6	96	15,111	1,511	2.16

Note: Based on 16-h/d operation at 75% load and 0.1 $/kWh.
a. Standard-efficiency and premium-efficiency motors from Reliance.
b. Energy-saver and standard-efficiency motors from General Electric.

TABLE 4. CAPITAL AND O&M COSTS OF NEW EQUIPMENT REQUIRED FOR THE POWER GENERATION PROPOSAL MADE IN THE CASE STUDY

Item	Investment cost, $	Annual cost, $
Gas generator	250,000	16,000
Gas holder	70,000	4,480
O&M costs for both		10,000
Total cost		30,480

$$P(\mathrm{kW}) = \left\{ \frac{m_a RT}{M_{air} n \eta_c} \right\} \left\{ \left(\frac{P_{out}}{P_{in}} \right)^n - 1 \right\} \quad (1)$$

All terms are defined in the Nomenclature box; values used for the case study are as follows:

m_a = 24,570/8/3,600 = 0.853
R = 8.314 kJ/k molK
T = 290 K
M_{Air} = 29.7 kg/kmol
n = 0.283
η_c = 0.9
P_{in} = 1 atm
P_{out} = 10 atm

Thus, the total energy shifted from peak to off-peak hours is then 250×8 = 2,000 kWh/d.

Aeration energy costs for this facility are then calculated as follows:

For 24-hour aeration
917 kWh/d × $0.02/kW*h* = $18.34/d
and
1,833 kWh/d × $0.08 $/kWh = $146.64/d
Total = $18.34/d + $146.64/d = $165/d

For 8-hour compression during off-peak hours
917 kWh/d × $0.02/*kWh* = $18.34/d
and
2,000 kWh/d × $0.02/kWh = $40/d
Total = $18.34/d + $40/d = $58.34/d

The simple calculations carried out above show that nearly $107 per day — totaling $40,000 per year — can be saved, simply by compressing the air during off-peak hours and then using it during peak hours.

Note that this energy-saving proposal will require the addition of a compression system and a tank to store compressed air. Average capital, operation and maintenance costs for these systems are shown in Table 2. As shown, the total, net energy-cost saving for the first year is about $8,000 (calculated as the $40,000/year saving, minus the costs added for the extra equipment).

Carrying out the same calculation methodology using a coarse-bubble diffuser instead of a micro-diffuser system — and hence using a coefficient of 1 kg O_2/kWh — yields an annual saving in electricity cost on the order of $80,000, but requires additional annual investment and O&M cost of about $55,000. Thus the net energy cost savings is about $25,000 for the first year.

PROPOSAL 2. USE VARIABLE-FREQUENCY DRIVES (VFDS)

As noted earlier, a VFD is an electronic controller that adjusts the speed of an electric motor. Most industrial alternating-current (a.c.) induction motors are designed to operate with a current that alternates in the direction of flow 50 or 60 times per second (Hz). If this frequency of alternation is changed, the speed of the motor speed changes.

By controlling the a.c., frequency and voltage using a VFD, the operator gains more efficient, continuous control, closely matching motor speed to the specific demands of the work being performed [*8*]. And, VFDs offer a "soft start" capability, ramping up the motor to its desired operating speed in a more gradual fashion. This helps to avoid abrupt starts that can subject motors to high torque and current surges — up to 10 times the full load current. Avoiding surges not only reduces stress on the motor system, but reduces maintenance and repair costs, and extends the motor life, as well.

In recent years, the use of VFDs has been growing to reduce energy use associated with pumping and aeration operations at WWTP — two energy-intensive applications that are particularly well-suited for VFDs. For applications where flow requirements vary, the traditional method for modulating flow is to throttle it, using mechanical devices, such as flow-restricting valves or moveable air vanes. However, this approach is akin to driving a car at full speed while using the brake to control speed — it uses excessive energy and often creates punishing conditions for the equipment.

Conversely, VFDs on pump motors allow operators to accommodate fluctuating demand over time, running pumps at lower speeds and drawing less energy while still meeting pumping needs. WWTP equipped with VFDs can maintain desired dissolved oxygen (DO) concentrations more consistently over a wide range of flowrates and biological loading conditions, by using automated controls that link DO sensors to VFDs on the aeration blowers.

In general, the energy savings resulting from VFDs can be significant. Even a small reduction in motor speed (say 20%) can significantly increase energy savings (by 50% or more).

Any pump motor that does not usually need to be run at full speed can substantially reduce its energy use by using a VFD. For instance, a 25-hp motor running 23 hours per day at adjusted speeds using a VFD (for instance, 2 hours at 100% speed; 8 hours at 75%; 8 hours at 67%; and 5 hours at 50%) can reduce energy use by 45%. At $0.10 kWh, this translates to a savings of $5,374 per year.

While the initial cost for VFDs may seem expensive, rapid payback is common, and reduced maintenance and longer equipment life can also contribute to overall lifecycle savings. And, many utilities offer financial incentives that can help to WWTP operators offset up front costs to install VFDs.

However, operators should note that, VFDs are not necessarily well-suited for all wastewater-treatment applications, such as applications where flow is relatively constant. Therefore, it is

Equation 5:

$$TC = C_i\left(\frac{A_i}{Ry}\right) + \frac{\left[C_{elec}E_f m_a^3 Ry^2 Z^2 hrs(6.5 + K_{el} + 2(\frac{A_i}{RyZA_{fan}})^2)\right]}{2\rho_a A_i^2 \eta_{fan}\eta_{motor}} + A_{ic} \quad (5)$$

important to calculate the potential benefits for each application based on system variables such as pump size, variability of flow, and total head [8].

PROPOSAL 3. REPLACE MOTORS WITH ENERGY-EFFICIENT ALTERNATIVES

Because pumps and blower motors account for 80–90% of the energy costs at WWTP, energy-efficient motors can play a major role in reducing a facility's operating costs. Although the initial cost of an energy-efficient motor can be 15–30% higher than that of a comparable standard motor, the long-term savings usually offset the higher capital cost in two years or less. Over a lifetime, the energy costs to operate a continuous-duty standard motor are 10–20 times higher than the original motor price [8].

Use the following formulas to calculate the annual energy savings (AES) and simple payback — that is, the time required for the savings from the investment to equal the initial cost — that can result from selecting a more-efficient motor.

$$AES = (E)(HPS)(LF)(hrs)\left(\frac{100}{E_{std}} - \frac{100}{E_{ee}}\right) \quad (2)$$

$$ACS = (AES)(Ur) \quad (3)$$

$$SP = IC/ACS \quad (4)$$

Table 3 provides a comparison between some common standard-efficiency motors and energy-efficient motors. Not surprisingly, the table shows that energy-efficient motors often pay for themselves over time.

Rebuilding (also called rewinding) an electric motor involves replacing the internal components. Although failed motors can usually be rewound as existing components age, it is often worthwhile to eventually replace damaged motors, and this provides a good opportunity to install newer energy-efficient models. Here are a few rules-of-thumb to consider when deciding whether to rewind a motor or purchase a new one:

- Replace an existing premium motor if the repair cost is more than 60% of the cost of a new one
- For intermittent- or low-usage applications, use the lowest-cost option that meets your operating requirements
- For single-shift operations in service for 2,000 h/yr, replace all low-efficiency motors below 30 hp with premium-efficiency motors. Consider repairing motors above 30 hp
- For two-shift operations running at 4,000 h/yr or more, replace all low-efficiency motors below 100 hp with premium-efficiency motors. Consider repairing motors above 100 hp
- For motors in continuous operation running at 8,760 h/yr or more, replace all low-efficiency motors with premium-efficiency motors

PROPOSAL 4. MAXIMIZE THE PRODUCTION AND USE OF BIOGAS AS A FUEL

Anaerobic digestion is one of the most widely used processes for stabilizing biosolids during wastewater treatment. The process involves the decomposition of the organic constituents of the biosolids via bacteria that thrive in the absence of oxygen. Apart from residual solids, the main products of anaerobic digestion are water and a biogas stream composed of methane, carbon dioxide, hydrogen sulfide, and other minor gaseous compounds.

This biogas has a heat value of roughly 20.5 MJ/m^3 — about 60% of the heat value of natural gas. Where applicable (in accordance with site-specific requirements or restrictions), biogas may be used as a fuel source, either off-site or within the plant, to improve the energy efficiency of wastewater-treatment processes.

The most easily adaptable in-plant uses for biogas are as a primary or backup fuel for general process heating, for space heating and cooling, for powering engines used to drive equipment directly and engines coupled with generators to drive equipment remotely, and for powering engines coupled with generators to produce general-purpose electrical power. At the WWTP, byproduct biogas can also be captured to offset the fuel requirements for solids incinerators, boilers used for the pasteurization of digested biosolids, and gas-fired biosolids dryers that are often used as part of the wastewater-treatment train.

In general, biogas generated during wastewater treatment can also be used to either generate energy or manufacture chemicals that can then be sold for use external to the plant, or the biogas stream itself can be sold to external parties.

To maximize energy saving associated with biogas capture, two issues must be considered: Maximizing biogas quantities and optimizing biogas utilization. Each is discussed below.

Maximizing biogas quantities

Suspended solids in wastewater are known to contribute a large part to the total BOD load, yet they also have a high capacity for biogas production. The most common ways to reduce aeration energy costs while maximizing biogas are listed below [10]:

Primary settling. Properly designed primary settling ponds can reduce influent BOD by as much as 35%, which creates a direct 35% reduction in the aeration requirements. Using anaerobic digestion, the reduced BOD load can be converted into biogas at a conservative conversion ratio of 0.4 m^3 biogas per 1 kg of BOD removed. As noted earlier, the main constituents of WWTP biogas are methane (60%–70%) and CO_2 (30%–40%), thus the caloric value of 1 m^3 of biogas is 5,000–6,000 kcal. To be conservative, we use 5,000 kcal for our case study.

Secondary settling. During aerobic digestion, the sludge that settles in secondary settling ponds is already partly digested. However, these biosolids still have substantial value for additional biogas production (which, as noted earlier, is about 0.1 m^3 biogas per 1 kg of BOD digested).

To demonstrate these numbers related to our case study, we assume the following:

BOD removed during primary settling is 5,500 kg BOD/d × 0.35 (because primary settling can reduce influent BOD by as much as 35%) = 1,925 kg BOD/d. Using the conversion ratio 0.4 m^3 biogas per 1 kg of BOD removed, this is converted into about 770 m^3 of biogas with a caloric value of 3,850,000 kcal/d.

Thus, in our case study, the biogas produced from the digestion of secondary sludge can be calculated this way: (5,500-1,925) kg BOD/d × 0.1 m^3 biogas/kg BOD = 357.5 m^3 biogas per day.

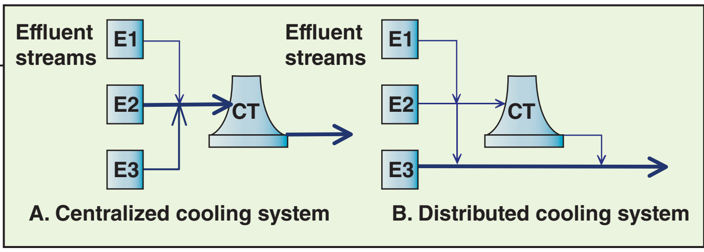


FIGURE 2. When a centralized cooling approach that will experience energy losses by mixing effluent streams with low temperatures (shown in Figure 2a) cannot be avoided, a distributed cooling system (shown in Figure 2b) should be considered to reduce energy losses

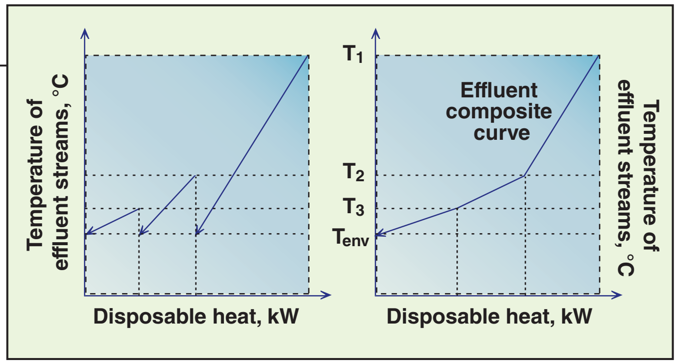


FIGURE 3. A key aspect of the ODEC process is the construction of the effluent profile composite curves. These curves are necessary to identify the maximum and minimum limitations for the flowrate of the inlet stream to the cooling tower (the feasible region). The optimum flowrate for the inlet stream to the cooling tower should be found in this feasible region in Stage 3

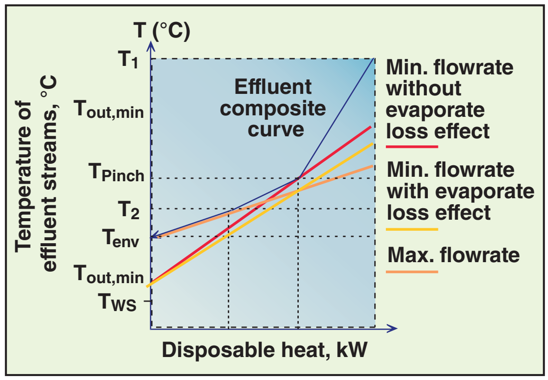


FIGURE 4. Once the effluent composite curve has been identified, users can identify feasible operational boundaries for designing the distributed cooling system

This amount has an equivalent energy value of 1,787,500 kcal/d.

Accordingly, the whole potential of biogas generation in this WWTP is about 5,637,500 kcal/d, which is roughly equivalent to 6,556 kWh/d.

General-purpose power gen

The efficient capture and use of byproduct biogas will require greater use of general-purpose power-generation systems right at the facility to make best use of the byproduct biogas. If systems are designed properly, biogas production from WWTP involving secondary treatment can be sufficient to provide up to 60–80% (or more) of the facility's total power needs.

In our case study, the production of 6,556 kWh/d energy that results from maximizing biogas generation can be converted to electricity using a gas engine with 32% efficiency. Accordingly, from this value, 2,000 kWh/d of electricity can be generated (which could be supplied to the plant as 200 kW of electricity per hour for each 10-h operation and most cost-effectively be used to offset power consumption from the grid during peak hours). The investments cost for the gas engine is about $250,000.

In some locations, it is also possible to sell this electricity back to the grid. Because biogas production tends to vary throughout the course of a day, it is a good idea to buffer biogas by the use of a gas holder (a vessel that allows operators to collect biogas as it is produced but use it at a predictable rate). To handle the 1,130 m^3/d of biogas produced in the case study (that is, the summation of 375.5 m^3/h biogas produced from the digestion of secondry sludge plus the 770 m^3/h of biogas produced from the reduced BOD load during primary settling), a 600-m^3 gas holder, in which more than 12 hours of biogas production could be buffered, would be appropriate. The cost related to the installation of a 600-m^3, double-membrane gas holder is about $70,000 (Table 4).

According to this proposal, the facility can generate 200 kW in 10 hours during peak periods — representing 200 kWh it does not need to buy from the national grid at a rate of 0.08$/kWh. At $160/d, this saves $58,400/yr.

As shown in Table 4, the cost to operate the power system in the plant will be $30,480/yr, so the net benefit is $58,400–$30,480=$27,920 (rounded to $28,000) per year.

PROPOSAL 5. DESIGN A DISTRIBUTED EFFLUENT-COOLING SYSTEM

At most WWTP, temperature restrictions often call for a cooling system to be used to make the streams suitable for discharge to regional waterways (such as rivers, lakes, estuaries or coastal water). Desired temperature reductions can be accomplished by simply installing cooling equipment and cooling all effluent streams prior to discharge. However, this can be expensive and inefficient.

For most WWTP facilities, the ability to design a distributed cooling system (one in which the various effluent streams are partially treated by the cooling tower, to achieve the same end result), allows for a smaller cooling tower to be used, compared to what is required for a conventional, centralized effluent-cooling system. This has favorable capital and operating cost implications.

Reducing the temperature of effluent streams prior to discharge often relies on a centralized cooling approach, whereby all streams are simply passed through a cooling tower (Figure 2a). In this approach, the cooling tower must be large because the flowrate of the blended inlet stream is high and the temperature driving force for cooling is low. This approach also has high energy requirements for pumps and air blowers.

By contrast, a distributed cooling system (such as that shown in Figure 2b) should be considered as another way to improve the energy efficiency of the WWTP. Using this approach, some nof the effluent streams are sent to the cooling tower while others bypass it. Downstream of the cooling tower, all streams are eventually blended, so that the final stream is at a temperature that is suitable for discharge. This allows for the use of a smaller cooling tower and lower energy costs without compromising the final discharge temperature.

The new Optimum Design method of a distributed Effluent Cooling (ODEC) system provides a systematic approach for identifying the most cost-efficient way to cool effluent streams of varying temperatures at a WWTP to meet the target discharge temperature, without wasting energy by simply cooling them all uniformly. Using the ODEC methodology, the optimum distributed cooling system is identified in five stages. During the first stage, an effluent composite curve is constructed, such as that shown in Figure 3 [*11*].

TABLE 5. EFFLUENT STREAM DATA USED FOR OPTIMUM DESIGN OF THE EFFLUENT COOLING SYSTEM IN THE CASE STUDY		
Effluent	Flowrate, kg/s	Temperature, °C
1	83.33	60
2	83.33	45
3	111.11	32

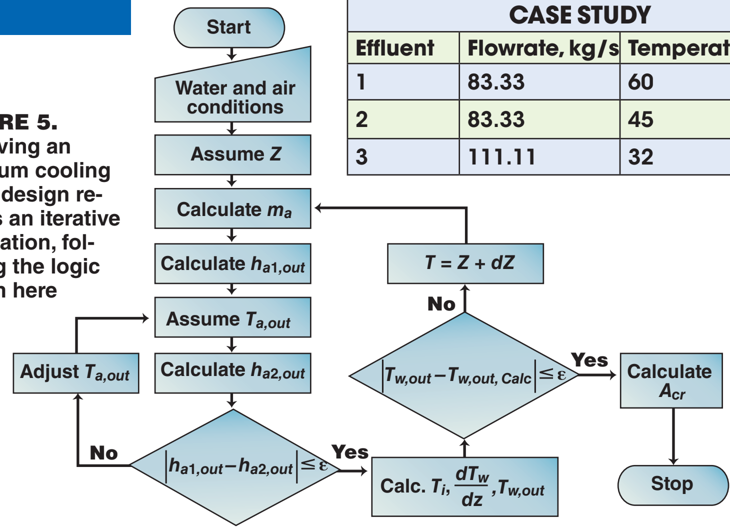


FIGURE 5. Achieving an optimum cooling tower design requires an iterative calculation, following the logic shown here

The cooling load requirements of individual effluent streams are graphically represented on a plot of temperature versus disposable heat, as shown in Figure 3a. All effluent streams are combined into a single composite curve by summing individual effluent disposable heat loads within the same temperature intervals (Figure 3b).

During the second stage, the feasible region is identified. The goal is to design the distributed cooling system that minimizes the overall cost to reduce effluent temperatures. First, the optimum flowrate for the inlet stream to the cooling tower must be defined, and maximum and minimum limitation should be identified, to create the "feasible region" (Figure 4).

The maximum flowrate for the inlet stream to the cooling tower is the summation of the flowrates of all effluent streams. This maximum amount is the upper boundary of the feasible region. The lower portion of the feasible region is the minimum flowrate of the inlet stream to the cooling tower that can provide the allowable discharge temperature to the environment after mixing with the bypassed effluent streams.

In the third stage, the optimum flowrate of the inlet stream to the cooling tower is determined by exploring the feasible area that was identified during the second stage.

Once the optimum flowrate of inlet stream to the cooling tower has been indentified, the modified cooling network is designed (in the fourth stage of the ODEC methodology) to achieve the target overall temperature reduction. In the fourth stage, we need to use the "grouping rules" (first introduced by Kim in 2001 [*11*]), which state that the temperature related to the confluence of the effluent composite curve and the cooling tower supply line should be considered. According to the rules, all effluent streams with temperatures above this amount should be sent to the cooling tower, while the ones with lower temperatures should bypass the cooling tower entirely. Finally the effluents with temperature equal to that temperature should be entered to the cooling tower partly to achieve the targeted flowrate for the inlet stream to the cooling tower.

Equation 13:

$$A_{i,opt} = \sqrt[3]{\frac{C_{elec} E_f m_a^3 Ry^3 Z^2 S[6.5 + K_{el} + 2(A_{fr} / A_{fan})^2]}{\rho_a{}^2 \eta_{fan} \eta_{motor} C_i}} \qquad (13)$$

During the final stage of the ODEC methodology, the cooling tower is designed to meet the targeted temperatures and flowrate conditions of all inlet and outlet streams.

As discussed below, the operating cost and the capital cost of the cooling tower have a different impact on the overall cost of the distributed cooling system [*12*], so efforts to design a distributed cooling system will require operators to reconcile tradeoffs between these two costs.

The total cost of the cooling tower, as the objective function, is expressed in Equation (5) [*13*] (Box, p. 38).

Cooling tower design model

In a countercurrent, wet cooling tower, the process typically consists of a gas phase (air) flowing upward and a liquid phase (water) flowing downward, with the tower internals creating a large interface between these two phases. The rate of energy transferred from the water is equal to the rate of energy gained by air (Equation 6):

$$Q_a = m_a (h_{a,out} - h_{a,in}) \qquad (6)$$

The air flowrate of the tower can be determined using Equation (7) (using a known water flowrate that is determined in the third stage):

$$m_a = \frac{m_w C_{pw}}{C_{pa}} \qquad (7)$$

Changes in the air-humidity ratio and the saturated-humidity ratio, both of which are a function of water temperature, vary from the top to bottom inside the tower and are given by Equations (8) and (9):

$$\frac{dT_w}{dz} = \frac{h_d A_{fr}}{m_w C_{pw}} (T_w - T_i) \qquad (8)$$

$$\frac{dT_a}{dz} = \frac{h_a A_{fr}}{m_a C_{pa}} (T_i - T_a) \qquad (9)$$

For the air-water system, heat and mass transfer coefficients are represented as a function of air and water flowrates. The related coefficients are given in Equations (10–12) [*14*]:

$$K_a A_{fr} = a_1 m_a^{b1} m_w^{c1} \qquad (10)$$

$$h_d A_{fr} = a_2 m_a^{b2} m_w^{c2} \qquad (11)$$

$$h_a A_{fr} = a_3 m_a^{b3} m_w^{c3} \qquad (12)$$

The optimum heat and mass transfer area can be calculated by Equation (13) [*13*]. (See the box above for Equation 13.)

The optimum cross-sectional area is given by Equation 14:

$$A_{Cr,opt} = \frac{A_{i,opt}}{RyZ} \qquad (14)$$

It is assumed that the cooling tower frontal area and cross-sectional area

TABLE 6. COMPARISON OF DESIGN PARAMETERS AND COSTS FOR THE CONVENTIONAL DESIGN METHOD & ODEC						
Design method	Flowrate, kg/s	Inlet temperature, °C	Outlet temperature, °C	Operating cost, k$/yr	Capital cost, k$/yr	Total cost, k$/yr
Conventional	277.77	44.31	30	45.52	41.79	87.31
ODEC	169.00	51.07	27.55	31.51	30.31	61.82

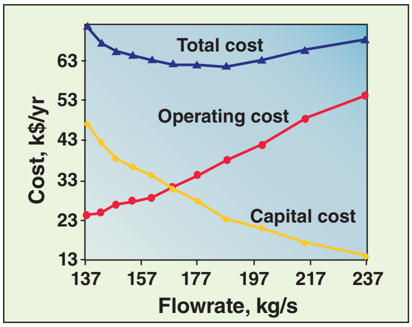


FIGURE 6. Overall cost impact of the distributed cooling system (in terms of both capital and O&M requirements) as a function of water flowrate. These relationships indicate that optimum water flowrate will require making a tradeoff between capital costs and operating costs

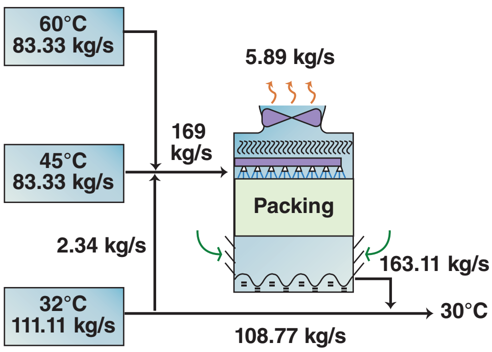


FIGURE 7. Shown here is the optimum effluent network determined by the ODEC, on the basis of the modified grouping design rules identified during the analysis

will be roughly equal. If the design is for a rectangular cooling tower, the frontal area is given by Equation (15):

$$A_{Cr} \approx A_{fr} = ZW \quad (15)$$

To achieve the optimum cooling tower design, an iterative calculation is required, as shown in Figure 5.

Illustrative example

Using the effluent streams whose data are shown in Table 5, the following example illustrates the optimum design of the effluent-cooling system, using the proposed ODEC design method. The following parameters were used:

- The electricity cost is 0.08 $/kWh
- The eliminator characteristic is 2.8×10^5 m^{-1}
- The eliminator friction coefficient is 4.6
- The operating period is 8,600 h/yr
- The environmental temperature discharge limit is 30°C
- The wet-bulb temperature is 20°C
- The minimum approach temperature is 5ºC

Figure 6 shows the effect of water flowrate on the capital and operating costs of the distributed cooling system. As shown, tradeoffs are often incurred. For instance, an increase in the flowrate may reduce the cooling tower capital cost but increase the operating cost. Efforts to determine the optimum water flowrate must consider this tradeoff. The optimum cooling line (which achieves the lowest total cost) will be one that is located between the maximum and minimum flowrates.

Table 6 compares design parameters and costs for a centralized cooling system and one designed using the ODEC methodology.

To achieve the targeted cooling-tower supply flowrate, Effluent 1 and Effluent 2 streams should be passed through the cooling tower completely and the Effluent 3 stream should be partially cooled and partially bypassed. Figure 7 shows the optimum effluent network produced with the ODEC on the basis of the modified grouping design rules.

Conclusion

The ability to maximize energy savings plays an important role in the reduction of overall wastewater-treatment costs. Engineers should identify available energy-saving approaches during the design phase and collaborate with plant staff to evaluate, select and implement the most appropriate strategies.

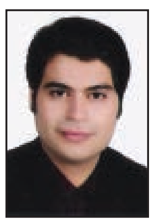
The options discussed here can help operators to keep their energy costs to a minimum, helping to reduce WWTP-related energy costs to 50% of the initial value (that is, values on the order of 0.2 –0.3 kWh/m^3, or a cost reduction of \$0.016/m^3 of wastewater). ■

Edited by Suzanne Shelley

References

1. Ingildsen, P. and Olsson, G., “Get More Out of Your Wastewater Treatment Plant,” ISBN 87-87411-01-6, Danfoss Analytical, 2001.
2. Kemira, “Handbok i Vattenvård,” Divisionen Vattenvård, Kemira Kemi AB, Helsingborg, 1998.
3. Perry, H.J., “Chemical Engineers’ Handbook,” McGraw-Hill, New York, 1950.
4. Alex, J., Ogurek, M., and Jumar, U., Simulation of energy consumption in wastewater treatment, The 2nd IWA Conference in Instrumentation, Control and Automation, Busan, Korea, 2005.
5. Copp, J.B., The COST Simulation Benchmark, Office for Official Publications of the European Communities, Luxembourg, 2002.
6. Hammer, M., “Waste and Wastewater Technology,” 5th edition, ISBN 0-13-097325-4, Prentice Hall, 2004.
7. Kadar, Y., and Siboni, G., Optimization of energy economy in the design and operation of wastewater treatment plants, 17th Congress of the World Energy Council, Texas, September 1998.
8. U.S. Environmental Protection Agency, Wastewater Management Fact Sheet (Energy Conservation), Office of Water, EPA-832-F-06-024, 2006.
9. U.S. Department of Environmental Protection, Bureau of Land & Water Quality, O&M Newsletter, 2002.
10. Otterlo, J.W.H., and Graaf, J.H.J.M., Practical experience with power generation at wastewater treatment plants in the Netherlands, Proceedings, Energy Savings in Water Pollution Control, IAWPRC, September, Paris, 1983.
11. Kim, J., Savalescu, L., and Smith, R., Design of cooling systems for eIuent temperature reduction, *Chem. Eng. Sci.*, 56: 1811–1830, 2001.
12. Prasad, M., Economic up gradation and optimal use of multi-cell cross flow evaporative water cooling tower through modular performance, *Applied Thermal Eng.*, 24:579–593, 2004.
13. Söylemez, M.S., On the optimum sizing of cooling towers, *Energy Conservation and Mgt.*, 42:783–789. 2001.
14. Ataei, A., Panjeshahi, M.H., Gharaie, M., Performance Evaluation of Counter-Flow Wet Cooling Towers Using Exergetic Analysis, *Transactions of the Canadian Society for Mechanical Eng.*, 32:499–511, 2008.
15. Panjeshahi, M.H., Ataei, A., Gharaie, M., Parand, R., Optimum design of cooling water systems for energy and water conservation, *Chem. Eng. Research & Design, 87:200–209*, 2009.
16. Coulson, J. M. and Richardson, J. F., “Chemical engineering: Fluid flow, heat transfer and mass transfer,” Oxford: Pergamon Press, 1996.
17. Kröger, D. G., “Air-cooled heat exchangers and cooling towers,” PennWell Corp. Oklahoma, 2004.

Author



Abtin Ataei is an Assistant Professor in the Graduate School of the Environment and Energy, Science and Research Branch of I. Azad University (I.A.U.; Daneshgah Blvd., Ashrafi Esfahani Ave., Ponak Square, P.O. Box: 14515-775, Tehran, Iran; Tel: +98-912-4383885, Fax: +98-21-44465383; Email: a-ataei@hotmail.com). He holds M.Sc. and Ph.D. degrees in energy engineering from the Science and Research Branch of I.A.U. Prior to joining the faculty of I.A.U. in 2003, he was a consultant for several Iranian sugar factories, a senior researcher at Sharif Energy Research Institute at Sharif University of Technology (Tehran). He has published more than 80 research papers in Iranian and international scientific journals and congresses. Recently, he was a post-doctoral researcher in the Green Energy Center, Dept. of Environmental Engineering, College of Engineering, Kyung Hee University (South Korea), researching energy and water-minimization techniques in the process industries.

Engineering Practice

Pressure Relief Requirement During External Pool-Fire Contingency

Santosh Arvind Katkar
Jacobs Engineering Group Inc.

A practical overview of the important factors that need to be considered when designing a pressure relief system

Relief system design is an important engineering activity throughout the chemical process industries (CPI). The main purpose of this task is to design a system that protects process equipment and piping against all possible causes of overpressure. It should relieve the excess pressure safely so as to protect personnel working in the facility from accidents, prevent damage to equipment and adjoining property, and comply with government regulations.

The principle causes of overpressure and guidance of plant design to minimize the effect of these causes are discussed in-depth in API STD 521 [*1*]. Among these causes, the external pool fire is a contingency that is very complex and dynamic in nature. (A pool fire is a turbulent diffusion fire burning above a horizontal pool of vaporizing hydrocarbon fuel where the fuel has zero or low initial momentum.) Although it is very difficult to cover every aspect of this contingency, important aspects are presented in this article for non-reactive systems. Reactive systems are beyond the scope of this article and interested readers should refer to DIERS Methodology [*2*]. A sample calculation and modeling results using commercial software are also presented at the end of this article.

BACKGROUND

Relief system design involves enormous efforts by process engineers who need to refer to all major engineering documents [such as process flow diagrams (PFDs), piping and instrumentation diagrams (P&IDs), heat and material balance and layout] as well as applicable codes, practices and standards. Among the tasks involved are the design of pressure relief devices, inlet-outlet piping, knockout drums, flares and vent stacks.

Codes and standards

The most important codes, standards and recommended practices that provide basic information on relief system design are as follows:

- API STD 520 Part I: Sizing, selection, and installation of pressure-relieving devices in refineries
- API RP 520 Part II: Sizing, selection, and installation of pressure-relieving devices in refineries
- ANSI/API STD 521: Pressure-relieving and depressuring systems
- API STD 2000: Venting atmospheric and low-pressure storage tanks
- DIERS Technology: Emergency relief-system design using DIERS (Design Institute of Emergency Relief System) Technology [*2*]
- NFPA 30: Flammable and combustible liquids code

In addition to these, other API, ASME, NFPA and OSHA standards, codes as well as local codes are also used in relief system design.

Most process engineers base their relief-system calculations on API standards and recommended practices. Guidelines and equations from these standards are referred to in this article, but no attempt is made to cover each design situation or confirm any design standard or recommended practice.

Important definitions

The definitions of important terms used in this article are as follows:

Relieving pressure is the pressure at the inlet of the pressure-relief device during relieving conditions and is equal to the sum of the valve set pressure and the overpressure. Refer to API STD 520 Part I [*3*] to determine the relieving pressure during present contingency.

Relieving temperature is the temperature at the inlet of the pressure relief device during relieving conditions.

Effective fire height is the height up to which the area is to be considered for fire exposure. This is based on the assumption that flames of a pool fire are not likely to impinge for long durations above this height.

Fire zone is an area of the process plant where fire is assumed to be prevailing at one instance. That means all equipment in this area are assumed to be engulfed by fire at once.

Fire case consideration

Considering the significant damage caused by fires, designing each pressure relief system for the fire contingency is a must. However, based on engineering practices, fire contingency can be omitted in some of following circumstances:

- When equipment is not located in or adjacent to areas containing flammable chemicals
- When equipment is located above a certain level from the grade or platform where potential accumulation of flammable liquid may occur. According to API STD 521 [*1*] this level is 7.6 m (25 ft) whereas according to NFPA [*4*] this level is 9.14 m (30 ft)
- When heat input from fire is insufficient to vaporize the liquid in the equipment within the reasonable amount of time required for corrective actions by operators
- When equipment can be emptied safely when such fire occurs

Assumptions

The exact behavior of the system impacted by an external pool fire is very complex and is dependent upon various factors, such as plant operation,

TABLE 1. EFFECTIVE WETTED SURFACE AREA			
No.	Type of equipment	Wetted Surface Area	Remark
1	Liquid full vessels	Total vessel surface area up to effective fire height	-
2	Surge drums	50% of total vessel surface area	Note 1
3	Knockout drums	25% of total vessel surface area	Notes 1 and 2
4	Tray columns	Surface area based on high liquid level in bottom plus surface area corresponding to liquid holdup of each tray up to effective fire height	-
5	Packed column	Surface area based on high liquid level in bottom plus surface area occupied by packing up to effective fire height	-
6	Horizontal tanks	Greater of the wetted area is equal to 75% of the total surface area or the surface area up to a height of 9.14 m above grade	
7	Vertical tanks	Total surface area of the vertical shell to a height of 9.14 m (30 ft) above grade	Note 3
8	Spheres and spheroids	Greater of the wetted area equal to 55% of the total surface area or the surface area up to a height of 9.14 m (30 ft) above grade.	-
9	Shell-and-tube heat exchangers (Note 4)	Safety valve on shell side: Surface area of exchanger based on higher liquid volume fraction in shell side within effective fire height	Note 5
		Safety valve on tube side: Surface area of channel heads	Note 6
10	Air Coolers (Note 7)	Bare area of tubes within the effective fire height plus projected area of tube bundle (only for induced draft type units) for tubes above effective fire height	Note 8

Notes:
1. If level is controlled consider surface area up to effective fire height.
2. If no liquid inventory, then should be treated as gas filled vessel.
3. Wetted area in contact with foundations or ground need not to be considered.
4. Present contingency to be considered for shell-and-tube heat exchangers depending upon their likelihood of getting blocked-in.
5. No credit generally taken for heat removal from tube side.
6. Any additional heat gain from shell side fluid also needs to be considered in calculations.
7. Only for liquid cooling and condensing services where liquid in not likely to drain in fire contingency.
8. For air coolers since fins are destroyed within the first few minutes of exposure to fire, bare tube area is to be considered in calculations.

NOMENCLATURE

Q	Heat input during external pool fire, W
F	Environmental factor
A_{ws}	Wetted surface area, m^2
k	Thermal conductivity of insulation at mean temperature, W/mK
T_f	Temperature of vessel contents at relieving temperature, °C
δ_{ins}	Thickness of insulation, m
W	Relief rate, kg/h
λ	Latent heat of vaporization, J/kg
M	Molecular weight of fluid, kg/kmol
P_1	Relieving pressure (bara)
P_n	Normal operating pressure, bara
A'	Exposed surface area, m^2
T_w	Recommended maximum wall temperature of vessel, K
T_1	Relieving temperature, K
T_n	Normal operating temperature, K
σ	Surface tension, kg/s^2
g	Gravitational constant, m/s^2
ρ_L	Density of liquid, kg/m^3
ρ_V	Density of gas, kg/m^3
U_e	Kutateladze entrainment velocity, m/s
h	Free board height, m

fire detection philosophy, shutdown procedure, fire-fighting system and so on. Even though these topics are covered in standards and codes, there are some conflicts in them and, moreover, they cannot cover all situations in detail. However, based on these standards and engineering experiences, the following assumptions can be considered in order to simplify the procedure to determine the pressure relief load:

- Each piece of equipment engulfed in the fire is assumed to be isolated, which means all heat and material inputs and outputs are assumed to be stopped. This assumption is based on the general plant operational practice to shut down the plant whenever fire is detected
- The area exposed for fire is considered the only area of equipment that is within the effective fire height
- Potential external fire is assumed to occur in only one particular fire zone
- In the absence of any governing factors, such as design and installation of a process facility, a fire zone area is assumed to be 230 to 460 m^2 (2,500 to 5,000 ft^2), as recommended by API STD 521 [*1*]
- All of the relief valves in one particular fire zone are assumed to relieve at the same time and at their maximum relieving flowrates. This is an important assumption during sizing calculations for relief-system discharge piping
- The amount of heat absorbed by equipment exposed to fire will depend on many factors, such as type of fuel, equipment shape and size, fire proofing and so on. However, heat input will be determined from empirical correlations that are based on test runs by applicable standards
- Since depressurizing systems and procedures can fail in the event of a fire, no credit for such system is recommended during sizing the relief device for fire contingency
- Similarly, an effective water deluge system depends on many factors, such as freezing weather, high winds, clogged systems, reliable water supply and equipment surface conditions. Hence, no credit is recommended by API STD 521 [*1*] for environmental factors used in the equations to determine the heat load due to fire
- Credit for insulation can only be taken if the insulation is a fireproofing insulation that meets certain criteria (discussed below)

RELIEF LOAD CALCULATION

Equipment containing liquids or gases will behave differently under the effect of fire. Equipment containing liquids with a "reasonable" boiling point has the benefit of a good heat-transfer rate between the equipment walls and the contained liquid, resulting in a slow temperature rise at the walls. On the other hand, for the equipment containing gases, vapors or supercritical fluids, there will be a poor heat-transfer rate between the equipment walls and the contained fluid, which results in a very rapid temperature rise of equipment walls. Therefore, separate procedures are to be followed to determine the fire case relief loads for these different situations.

Equipment containing liquid

The following procedure is adopted for determining the relief loads for equipment containing liquids:

1. Determination of wetted area. All empirical equations used to determine the heat absorption rate are based on the wetted surface area, A_{ws}, exposed to fire. As a general practice,

EQUATIONS FOR CALCULATING HEAT ABSORPTION RATE

I. Equipment with design pressure greater than 1.034 barg (15 psig)

A. For equipment with adequate drainage and fire fighting facility

$$Q = 43,200 \cdot F \cdot A_{ws}^{0.82} \quad (1)$$

B. For equipment without adequate drainage and fire fighting facility

$$Q = 70,900 \cdot F \cdot A_{ws}^{0.82} \quad (2)$$

Adequate drainage facility here can be defined as the facility that shall be able to carry the flammable/combustible liquid and firewater away from the equipment. Adequate fire fighting facility can be defined as the facility that shall be activated as soon as the fire begins.

The environmental factor *F* in equations above and hereafter is the credit factor primarily for fire proofing insulation and not for general thermal insulation. The general thermal insulation is destroyed by combustion during first few minutes of exposure to fire. The fire proofing insulation, however, is such that it meets the following criteria:

- Functions effectively up to the approximate temperature of fire for up to two hours
- Shall not be dislodged by fire fighting streams

Table 2 is quick reference for environmental factors to be used based on API STD 521 [*1*]. Equation (3) is based on thermal conductivity and thickness of insulation can be used to determine the environmental factor.

TABLE 2. ENVIRONMENTAL FACTORS

Sr. no.	Type of equipment	Insulation conductance, W/m^2K	Factor
1	Bare Vessel / Tank		1.0
2	Insulated vessel / tank	22.7	0.3
		11.4	0.15
		5.7	0.075
3	Water Spray	-	1
4	Depressurization and emptying facility	-	1
5	Earth covered storage	-	0.03
6	Below Grade Storage	-	0

TABLE 3. FOR TANKS WITHOUT WEAK ROOF-TO-SHELL ATTACHMENTS

Wetted surface area, m^2	Design pressure, barg	Heat input, W
$A_{ws} < 18.6$	≤ 1.034	$Q = 63,150A_{ws}$
$18.6 \le A_{ws} \le 93$	≤ 1.034	$Q = 224\ 200A_{ws}^{0.566}$
$93 \le A_{ws} < 260$	≤ 1.034	$Q = 630,400A_{ws}^{0.338}$
$260 \le A_{ws}$	Between 0.07 and 1.034	$Q = 43,200A_{ws}^{0.82}$
$260 \le A_{ws}$	≤ 0.07	$Q = 4,129,700$

TABLE 4. FOR SINGLE-WALL REFRIGERATED STORAGE TANKS

Wetted surface area, m^2	Design pressure, barg	Heat input, W
$A_{ws} < 18.6$	≤ 1.034	$Q = 63,150A_{ws}$
$18.6 \le A_{ws} < 93$	≤ 1.034	$Q = 224,200A_{ws}^{0.566}$
$93 \le A_{ws} < 260$	≤ 1.034	$Q = 630,400A_{ws}^{0.338}$
$260 \le A_{ws}$	≤ 1.034	$Q = 43,200A_{ws}^{0.82}$

$$F = \frac{k \cdot (904 - T_f)}{66,570 \cdot \delta_{ins}} \quad (3)$$

II. Equipment having design pressure from vacuum to 1.034 barg (15 psig)

A. For non-refrigerated aboveground tanks

i. For tanks with weak roof-to-shell attachment: These tanks do not require any emergency venting as roof to shell connection fails preferentially to any other joints.

ii. For tanks without weak roof-to-shell attachment: The equations in Table 3 can be used, depending on wetted surface area and design pressure.

B. Refrigerated aboveground and belowground tanks

i. For single-wall refrigerated storage tanks: The equations in Table 4 can be used, depending on the wetted surface area and design pressure.

ii. For double-wall refrigerated storage tanks: Fire case analysis of such tanks is very complex and very little information is available about them in literature. During early stages of fire, heat gain will be utilized for expansion of vapors between the walls. It will take several hours for vaporization of liquid in these tanks.

III. Air Coolers

As suggested by API STD 521 [*1*] the following equations are to be used for air coolers in liquid cooling service.

A. For air coolers with adequate drainage and fire fighting facility

$$Q = 43,200 \cdot A_{ws} \quad (4)$$

B. For air coolers without adequate drainage and fire fighting facility

$$Q = 70,900 \cdot A_{ws} \quad (5)$$

Due to the large surface area of air coolers, their heat-absorption rates are very large resulting in the requirement of extremely large fire-case relief load. This is the reason process engineers employ the other means of mitigating the fire relief for them, such as location and an automatic water-deluge system. ❏

API STD 521 [*1*] guidelines can be used to determine the wetted surface area. Table 1 is a consolidated guideline for wetted surface area to be considered, based on available Refs. [*1, 5* and *6*] and engineering practices. Engineering judgment, however, will be needed by the design engineers in evaluating the surface area exposed to fire.

Since the associated liquid-filled piping will also contribute to vapor generation, either the surface area corresponding to larger diameter pipes associated with process equipment or 10–15% of the calculated wetted area is to be considered in calculating the total wetted surface area for fire.

2. Determination of heat absorption rate. Various empirical equations to calculate the heat absorption rate, *Q*, are available in the literature; the appropriate equation based on applicable conditions needs to be used. The equations mentioned in API STD 521 [*1*] are for pressure equipment, and equations mentioned in API STD 2000 [7] are for atmospheric and low pressure tanks. The box above provides a summary of the key equations based on the API standard.

3. Determination of latent heat of vaporization. Before determining the final relief rate, the engineer has the important task of determining the latent heat of vaporization of the contained liquid.

For equipment containing a single component liquid, the latent heat of vaporization can be easily determined based on relieving conditions. The relieving conditions are the relieving pressure and corresponding boiling temperature.

However, for vessels containing multi-component liquids, determining an accurate value of latent heat of vaporization is quite difficult. For such vessels, composition of liquid and vapor changes as the lighter fractions evaporate early during fire. Relief rate — and ultimately the relief device size calculation that is based on initial latent heat and other physical properties — is not always conservative, so a time-dependent model is recommended by API STD 521 [*1*].

With computer simulation programs readily available to today's process design engineers, latent heat of vaporization can be easily and accurately determined if proper care is taken during the use of these programs. Further information on getting conservative properties, including latent heat of vaporization with step-by step vaporization, can be found in Refs. [*6* and *15*]. One simplified and fairly conservative approach is to determine the relief device area, considering that the vessel is filled with a single component each time, and selecting the maximum relief area among them. This approach is widely used for multipurpose vessels typically used in pharmaceutical industries.

In case computer simulation programs are not available, Figure A.1. from API STD 521 [*1*] can be used for single component paraffins, mixtures of paraffins that have slightly different relative molecular weights, isomer hydrocarbons, aromatic compounds and cyclic compounds. The vapor pressure in this figure is the relieving pressure of the system, and correspondingly the relieving temperature and latent heat is to be determined based on the average molecular weight of components.

In case of relieving conditions near the critical region, the latent heat of vaporization approaches zero as sensible heat dominates. For such conditions API STD 521 [*1*] suggests using a minimum latent heat value of 115 kJ/kg (50 Btu/lb) as an approximation.

4. Determination of relief rate. After determining the of heat input, Q, the relief rate, W, can be easily calculated based on following simple equation:

$$W = 3{,}600 \cdot \frac{Q}{\lambda} \quad (6)$$

Equipment containing gases, vapors or supercritical fluids

As mentioned above, the heat transfer between equipment walls and the contained fluid is very poor when the contained fluid is a gas, vapor or supercritical fluid. This results in a very rapid temperature rise in the equipment walls causing equipment failure due to heat stress even before the internal pressure reaches the set pressure of a pressure-relief safety valve. Section 5.15.4.1 of API STD 521 [*1*] clearly indicates that the pressure relief device does not provide sufficient protection from equipment rupture. The other means of protection for such vessels are as follows [*1* and *13*]:

- Cooling the equipment surface by a water-water deluge system
- Providing automatic vapor depressurizing systems
- Locating equipment such as to eliminate or reduce the effect of fire
- Installing external fire-proofing insulation
- Using reliable fire-monitoring system and a rapid-action fire-fighting team

Even though it is unlikely that a pressure relief device will protect the equipment, the empirical equation to determine the relief rate as suggested by API STD 521 [1] for this type of equipment is as follows:

$$W = 2.77 \cdot \sqrt{MP_1} \cdot \left[\frac{A' \cdot (T_w - T_1)^{1.25}}{T_1^{1.1506}} \right] \quad (7)$$

This equation is modified to suit the unit system used in this article and is based on various assumptions that need to be consider before using it. The temperature T_w is the recommended maximum wall temperature, 593°C (1,100°F), that can be used for carbon-steel plates. The exposed surface area, A', is calculated in the same way as the wetted surface area earlier, based on possible source of fire.

Relieving conditions in this case are the relieving pressure, as defined earlier, while relieving temperature is calculated by following equation.

$$T_1 = \left(\frac{P_1}{P_n} \right) \cdot T_n \quad (8)$$

Equipment that is internally insulated and contains a single phase (above critical point) at relieving conditions has to be treated in the same manner as the equipment containing gases.

Equipment containing low liquid inventory

Low-liquid-inventory equipment can be defined as the equipment in which all the contained liquid could vaporize within 15 to 20 min. If the vessel pressure when the last drop of liquid vaporizes is less than the device set pressure, then the relief load to be considered is based on the procedure for gas filled equipment. However, if the vessel pressure when the last drop of liquid vaporizes is more than relief device set pressure, the relief load to be considered will be the maximum of relief load calculated based on considering liquid filled or gas filled vessel. Refs. [*13* and *14*] can be consulted for a more detailed description and the required equations for such vessels.

Equipment containing high boiling liquids

This equipment behaves similar to that containing gases, and a pressure relief device is not likely to provide sufficient protection from equipment rupture. In order to protect equipment in this situation, the design temperature must be higher than the boiling temperature of the contained liquid at relieving pressure. This is very rare, and hence, other means of protection need to be used, as discussed above for gas filled equipment. The relieving capacities, however, are determined based on thermal expansion if the vessel is liquid full, and a procedure similar to those explained above are adopted if the vessel is not liquid full. Refer to API STD 521, section 5.14 [*1*] for calculating the relief load due to hydraulic expansion of liquid.

Mixed phase relief

One of the significant problems that a process engineer needs to deal with is to design the relief system in present contingency for single phase (vapor or liquid) or for mixed phase (vapor-liquid). Generally a mixed phase flow requires a larger relief area than vapor or liquid phase flow. Traditionally it has been assumed that relief is generally a vapor phase relief in the present contingency. However, it has been found that relief can be two-phase relief depending upon the following factors:

1. Nature of liquid. It is the foamy or non-foamy behavior of the liquid that results in the possibility of having mixed phases during pressure relief. It has been observed that relief from non-foamy liquid is generally a vapor phase relief. API STD 521 [*1*] also says that a relief system need not be designed for two phases for non-foamy systems. However, it is not possible to predict the foamy behavior of liquid from mere physical properties; hence the conservative approach is to consider the liquid as foamy whenever there is doubt. A few guidelines to classify liquid as foamy are as follows:

- Liquids having viscosity greater than 100 cP
- Liquid containing surfactants
- Dirty liquids containing solids
- Multi-component liquids with wide range of boiling points
- Chemically reacting liquids
- Liquid with more than one liquid phase

2. Initial fill level. Even though a liquid might be non-foamy, it has been observed that if the initial fill level in the vessel is above a certain level, pressure relief can be mixed phase. So far there are no well defined standards available above which mixed-phase relief is to be considered. Guidelines as provided in Ref. [*8*] however can be used for non-reactive systems for low-pressure storage tanks. A conservative approach is to consider the two-phase relief when initial liquid level is above 20% for foamy liquids and above 80% for non foamy liquids. However, small vessels having diameters less than 3 m do require more free board height.

Many references are available for predicting the possibility of mixed phase behavior. One of the simplest approaches is as explained in Ref. [*9*]. This is based on calculating a minimum free-board height, h, which is the height between the vessel nozzle on which relief valve is mounted and the liquid level. If the fill level at relieving conditions is above the calculated minimum free-board height, venting is to be considered as mixed phase venting. The following equations from Ref. [*10*] are used to calculate the minimum free-board height.

$$h = \sqrt{\left(\frac{W}{2\pi U_e \rho_v}\right) \cdot \frac{1}{3{,}600}} \qquad (9)$$

In this equation U_e is the entrainment velocity — known as the Kutateladze entrainment velocity [*11*] — and is calculated from Equation (10).

$$U_e = 3\left(\frac{\sigma \cdot g \cdot \rho_L}{\rho_v^2}\right)^{1/4} \qquad (10)$$

Fire duration

One of the aspects that has not been discussed much in the standards is the need to consider the duration of fire and the present contingency together. Based on the duration for a fire fighting team to take an action against present contingency, the fire duration can be ignored if vessel pressure at the end of this duration is not going to reach the relief-valve set-pressure.

The duration for the fire fighting team to take an action will depend upon the complexity of the plant and should not be more than 15–20 min [*13*]. This duration is based on the fact that an un-wetted steel plate, 25 mm (1 in) thick, takes about 12 min to reach 593°C (1,100°F) and 17 min to reach 704°C (1,300°F) when the plate is exposed to an open fire [*1*]. Hence, present contingency can be eliminated for those vessels having vessel pressure at the end of 20 min, well below the relief device set pressure. This duration of 20 min needs to be confirmed and mentioned in the relief system design basis.

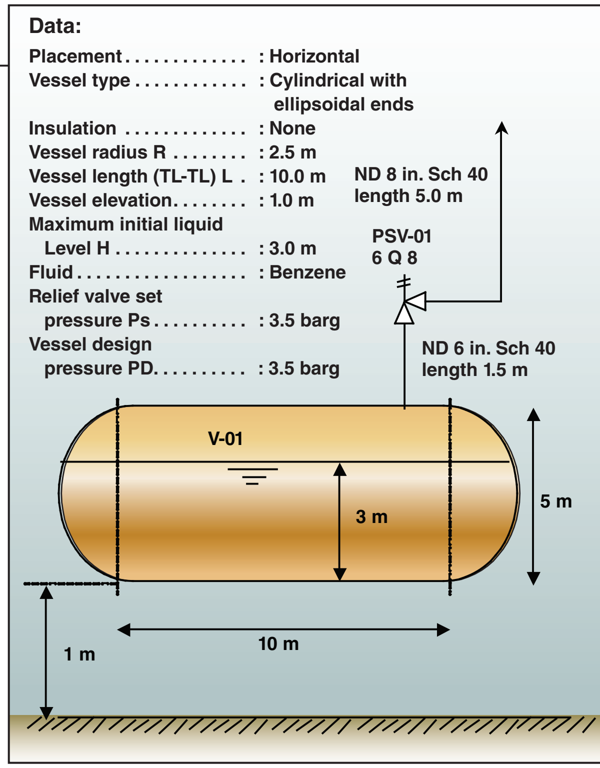


FIGURE 1. The vessel and data for Example 1

EXAMPLE CALCULATIONS

Two examples are illustrated here, one for a vessel containing liquid and another for vessel containing gas. Commercial simulation software is used to generate the properties required. The absolute barometric pressure for both problems is assumed to be 1.0132 bar.

Vessel containing liquid

The first example concerns a horizontal vessel containing benzene. The dimensions and other data needed for the calculation are shown in Figure 1.

Determination of wetted surface area. Ref. [*12*] is used to determine the wetted surface area of partially filled vessels. The wetted surface area of shell is given by

$$2 \cdot L \cdot R \cdot \cos^{-1}\left(\frac{R-H}{R}\right) \qquad (11)$$

$$2(10)(2.5) \cdot \cos^{-1}\left(\frac{2.5-3.0}{2.5}\right)$$

$= 88.61\ m^2$

The wetted surface area of the two elliptical heads is given by Equation (12), (see box, p. 47), where F is the fractional liquid level ($= H/2R$) and ϵ is the eccentricity of the elliptical head (= 0.866 for the common case of a 2:1 ellipse). Entering the values into Equation (12) gives 31.10 m^2. The wetted area for the vessel is therefore 88.61 + 31.10 = 119.71 m^2. The wetted area for the piping is assumed to be 10% of the

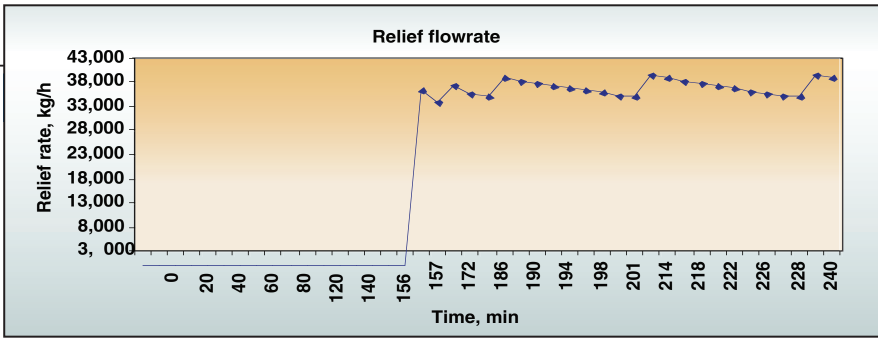


FIGURE 2. Simulation results for Example 1 showing the relief rate over time when the vessel is engulfed in an external fire

Equation 12

$$\pi \cdot R^2 \left[(F-0.5)\cdot\sqrt{1+12\cdot(F-0.5)^2}+1+\frac{1}{4\varepsilon}\cdot\ln\left(\frac{4\varepsilon(F-0.5)+\sqrt{1+12\cdot(F-0.5)^2}}{2-\sqrt{3}}\right)\right]$$

TABLE 5. EXAMPLE 2 DATA

Placement	Vertical
Vessel Type	Cylindrical with hemi-spherical ends
Insulation	None
Vessel radius, R	1.0 m
Vessel length (TL-TL) L	6.0 m
Vessel elevation	2.0 m
Fluid	Air
Relief valve set pressure, P_s	7.5 barg
Normal operating pressure, P_n	5.5 barg
Normal operating temperature, T_n	35°C
Maximum wall temperature, T_w	593°C

calculated wetted area, or 11.97 m^2, so the total wetted area is 119.71 + 11.97 = 131.68 m^2.

Determination of heat absorption rate. Assuming that the facility has adequate drainage and a fire fighting system in place and the vessel is designed for 3.5 barg pressure, Equation (1) can be used here to determine the heat input, Q:

$$Q = 43{,}200 \cdot F \cdot A_{ws}^{0.82}$$

Q = 43,200 (1)(131.68)$^{0.82}$
= 2,363,144 W
= 2,363.1 kW

Determination of the latent heat of vaporization. Latent heat of vaporization is obtained through commercial simulation software at relieving conditions, which are as follows.
Relieving pressure = P_1
= 1.21 P_s (21% overpressure)
= 4.325 barg
Relieving temperature = T_1
= 145°C (from simulation program)
Latent heat of vaporization = λ
= 347 kJ/kg (from simulation)

Determination of relief rate. Inputting the values obtained above into Equation (6), the relief rate, W, is
W = 3,600 Q/λ
= 3,600 [(2,363.1)/347]
= 24,516 kg/h
A commercial simulation program is available to simulate the vessel engulfed in external fire. Figure 2 is the vent flowrate for the above mentioned vessel with respect to time using such a program. This program works in rating mode, and hence, the details of safety relief valve and inlet-outlet piping as shown in Figure 1 are used to get the profile plotted in Figure 2.

Vessel containing gas

The data for this second example are listed in Table 5.

Determination of wetted surface area: Equations from Ref. [*12*] are again used to determine the exposed surface area of vessels. The exposed surface area of shell is the area of a cylinder with radius R.

$2\pi RL = 2\pi(1)(6) = 37.70$ m^2

The exposed surface area of heads is the area of a sphere

$4\pi R^2 = 4\pi(1)^2 = 12.57$ m^2

The exposed surface area for piping, again assuming 10% of calculated wetted area, is 5.03 m^2. Therefore, the total wetted surface area is

37.70 + 12.57 + 5.03 = 55.29 m^2

Determination of relieving conditions. The relieving pressure, P_1 is

1.21 x P_s (21% overpressure)
= 9.075 barg

The relieving temperature, T_1 , is determined from Equation (8) to be

$T1 = (P_1/P_n)T_n$
= [(9.075 + 1.0132)/(5.5 + 1.0132)]× (35 + 273.16) = 477.3 K = 204.1°C.

The relief rate, as determined from Equation (7), is

W = 2.77[28.84 × (9.075 + 1.0132)]$^{1/2}$ × {55.2[(593 + 273.16) – 477.3]$^{1.25}$/ (477.3)$^{1.1506}$}
W = 3,733 kg/h. ■

Edited by Gerald Ondrey

References:

1. Pressure-Relieving and Depressuring Systems, ANSI/API Standard 521, 5th ed., January 2007.
2. Fisher, H. G., others, Emergency Relief System design using DIERS Technology, AIChE, 1992.
3. Sizing, Selection, and Installation of Pressure-Relieving Devices in Refineries, Part-I, API Standard 520, 8th ed., December 2008.
4. Flammable and Combustible Liquids Code, NFPA 30, 2008 ed.
5. Ludwig, E. E. "Applied Process Design, Volume 1," 3rd ed., Gulf Publishing, 1995.
6. Wong W. Y., Fire, Vessels and Pressure Relief Valves, *Chem. Eng.*, May 2000, pp. 84–92.
7. Venting Atmospheric and Low-Pressure Storage Tanks, API Standard 2000, 5th Edition, April 1998.
8. Fisher, H. G., and others, Protection of Storage Tanks from Two-Phase Flow due to Fire Exposure, *Process Safety Progress*, July 1995.
9. Fauske, H. K. Properly Size Vents for Nonreactive and Reactive Chemicals, *Chem. Eng. Prog.*, February 2000.
10. Epstein, M., others, The Onset of Two-Phase Venting via Entrainment in Liquid-Filled Storage Vessels Exposed to Fire, *J. Loss Prev. Process Ind.*, 2 (1), p. 45, 1989.
11. Kutateladze, S. S., Elements of the Hydrodynamics of Gas-Liquid Systems, *Fluid Mechanics — Soviet Research*, 1, p. 29, 1972.
12. Doane, R.C. Accurate Wetted Areas for Partially Filled Vessels, *Chem. Eng*, December 2007, pp 56–57.
13. Wong W. Y., Improve the Fire Protection of Fire Vessels, *Chem. Eng.*, October 1999, pp. 193–196.
14. Mofrad S. R. others, Designing for Pressure Release during Fires — Part 1, *Hydrocarbon Process*, November 2007, pp. 65–67.
15. Mofrad S. R. et. al. Designing for Pressure Release during Fires – Part 2, *Hydrocarbon Process*, December 2007, pp. 117–121.

Author

Santosh Arvind Katkar is a process engineer at Jacobs Engineering Group Inc. (29, International Business Park #03-01, Acer Building, Tower A, Singapore – 6009923. Phone: +65 6890 4967; Fax: +65 6899 1619; Email: Santosh.Katkar@jacobs.com). He has over 8 years of experience in petroleum refining, petrochemical and other process industries with leading engineering organizations such as Fluor Daniel India and Lurgi India. He earned his M.Tech from Indian Institute of Technology (Delhi) and B.Tech from University Department of Chemical Technology (Jalgaon).

Updating the Rules For Pipe Sizing

The most economical velocity in piping has shifted downward over the last 40 years

Alejandro Anaya Durand,
Maria Jose de Villafranca Casas,
Adriana Shunashi García Cornejo,
Daniela Jara Carranza,
Francisco Javier Pacheco Román,
Ricardo Gabriel Suárez Suárez,
Juan Sampieri Espinoza,
Luis Francisco Villalobos Vazquez de la Parra

Faculty of Chemistry, UNAM

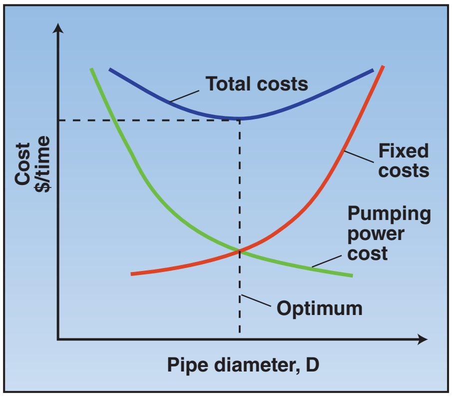


FIGURE 1. Fixed costs rise as the pipe diameter increases. Power costs fall as the pressure drop falls. The sum of these two has a minimum

Pipe sizing calculations include certain values that are time dependent, such as costs. While some costs rise, others decrease over time. It is the designer's task to ensure that the total cost is minimized. For fluid flow calculations, heuristic criteria are often used, which is the main reason why these values must be updated from time to time. In this article, recommended velocities are updated for several materials of construction, and other velocities for new materials are calculated, using the Generaux Equation [*1*], shown in the box on p. 50.

Process design is one of the most important tasks in engineering. In the development, optimal use of resources must be accomplished in order to reach equilibrium between minimum cost and maximum efficiency.

Engineers tend to use heuristic formulas to make quick estimates. Such calculated estimations are accurate enough for grasping a quick overview of the desired process.

Some of these calculations involve certain factors that change over the years. Nevertheless, the values frequently used as inputs in these equations are over thirty years old, driving estimations even further away from reality [*2*].

An example of these phenomena is the determination of the recommended velocity for a fluid in pipe sizing. The velocity is intrinsically related to fluid properties and a host of economic parameters, including energy and pipe material costs. It's important to remember that pipe diameter is directly proportional to its cost.

Since 1968 prices have dramatically changed due to inflation. In 1998 it was demonstrated that the most economical velocity in piping had shifted downward over the preceding 30 years [*2*]. In that paper, recommended velocities were recalculated using the Generaux equation [*1*] with parameters and costs of 1998 derived by the Marshall & Swift Index (see p. 64) [*3*]. Similarly recommended velocities are updated in this article. We compare 1998 values with the actual calculated ones (2008) and calculate new values for pipe materials other than steel, such as brass and aluminum.

Defining optimum

For pipe design, several criteria have to be taken into account. Common criteria used are recommended velocity, economics and other operational parameters.

Ultimately, an economical criterion is the decisive factor for determining a pipeline design. This particular analysis is meant to find the lowest total cost, which is the sum of capital and operational costs. By determining this minimum a number of variables are also minimized.

Fixed costs are practically independent of time and production volume. Examples of these are rent, taxes and depreciation. Operational costs, on the other hand, are the variable costs, which typically include raw materials, man power and energy services, and fixed operational costs.

A practical way to find the optimal cost is to plot capital and operational costs (with the same scale) and then add these values to form a new function that will have a minimal value (the optimal value) as shown in Figure 1.

Optimum equation

Although there are several rules for calculating the optimum pipe diameter, this paper only considers the Generaux equation, shown in the box on p. 50. This equation determines the fluid velocities required to obtain the most economic pipe diameter.

Updated recommendations

Price changes have a great impact on the parameters used in the Generaux equation. Table 1 shows the influence of the change in energy and material costs as measured by the Marshall & Swift Index [*2*]. Some of the values of these parameters were derived in order to obtain updated ones that could be more in line with 2008 costs.

Figure 2 and Table 2 show a comparison of the velocities calculated. Updated fluid velocities of carbon-steel

TABLE 1. VALUES USED IN THE GENERAUX EQUATION

Terms	Carbon steel 1998	Stainless steel 1998	Carbon steel 2008	Stainless steel 2008	Aluminum 2008	Brass 2008
n	1.35	0.7793	1.472	0.924	0.769	0.907
x	29.52	130	6.607	30.7	22.26	32.3
Le′	2.74	2.74	2.74	2.74	2.74	2.74
M	0.102	0.102	0.064	0.064	0.064	0.064
E	0.5	0.5	0.5	0.5	0.5	0.5
P	150	150	150	150	150	150
K	0.04	0.04	0.07	0.07	0.07	0.07
Y	365	365	365	365	365	365
Φ	0.55	0.55	0.55	0.55	0.55	0.55
Z	0.1	0.1	0.1	0.1	0.1	0.1
F	6.7	7.5	6.5	7.4	7.1	7.2
a + *b*	0.2	0.2	0.2	0.2	0.2	0.2
a′ + *b′*	0.4	0.4	0.4	0.4	0.4	0.4

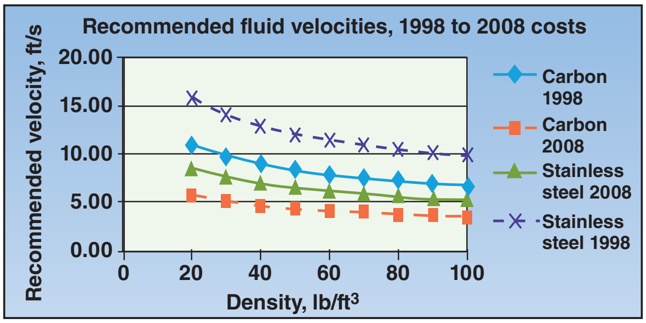


FIGURE 2. Comparison between the recommended fluid velocities from 1998 & 2008

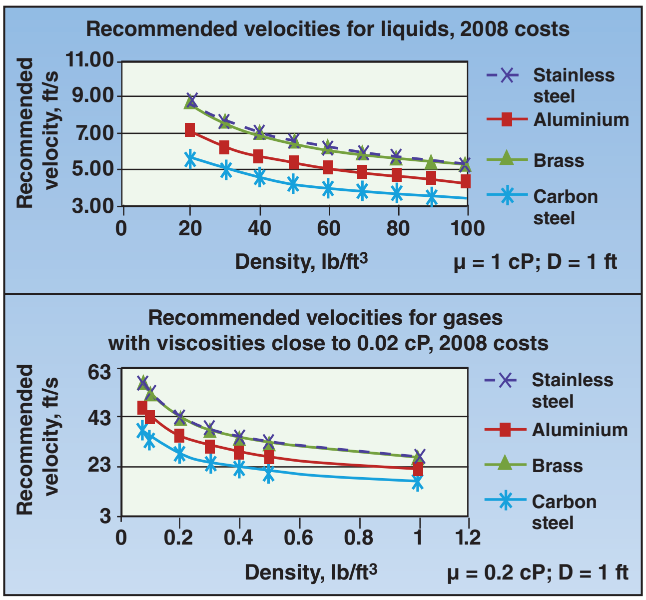


FIGURE 3. Recommended velocities for gases (a) and liquids (b) according to 2008 prices. Recommended velocities tend to decrease as years pass by

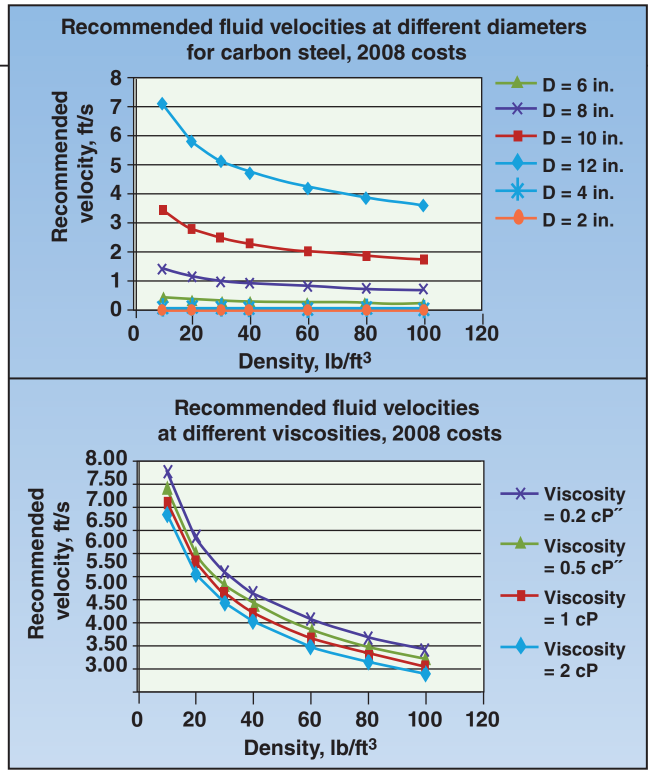


FIGURE 4. Plots of recommended velocities versus different viscosities and diameters show that viscosity has no significant influence in recommended velocity. At higher diameter, economic velocities are also higher

TABLE 2. UPDATED RECOMMENDED FLUID VELOCITIES (2008 COSTS)

Carbon Steel 2008							
Density, lb/ft³	100	62.4	50	1	0.1	0.075	0.01
Viscosity, cP	1	1	1	0.02	0.02	0.02	0.02
Recommended velocity, ft/s	3.57	4.11	4.38	17.38	34.34	37.39	67.85
Stainless Steel 2008							
Density, lb/ft³	100	62.4	50	1	0.1	0.075	0.01
Viscosity, cP	1	1	1	0.02	0.02	0.02	0.02
Recommended velocity, ft/s	5.42	6.23	6.65	26.37	52.10	56.73	102.95
Aluminum 2008							
Density, lb/ft³	100	62.4	50	1	0.1	0.075	0.01
Viscosity, cP	1	1	1	0.02	0.02	0.02	0.02
Recommended velocity, ft/s	4.48	5.15	5.50	21.79	43.06	46.88	85.08
Brass 2008							
Density, lb/ft³	100	62.4	50	1	0.1	0.075	0.01
Viscosity, cP	1	1	1	0.02	0.02	0.02	0.02
Recommended velocity, ft/s	5.43	6.25	6.67	26.44	52.25	56.89	103.24

pipe are about 48% lower than the 1998 recommendations; the same goes for stainless-steel pipe with a 45% decrease. The influence of diameter and viscosity is shown in Figures 3 and 4.

Cost evolution

In the midst of comparison between energy and capital costs, the energy cost has proved to have a greater impact. This cost can be defined by the variable K, which surprisingly has increased by a factor of 1.75 since 1998. While energy costs increase in an inversely proportional way, recommended velocities tend to shift down over time despite involving a higher initial investment in piping design (material costs).

Sample calculation No. 1

Consider a pipeline for the following conditions.

- Pipe: stainless steel
- Flow: Q = 250 gal/min = 0.557 ft³/s
- Liquid: water at 60°F
- Density: ρ = 62.4 lb/ft³

Using the set of fluid velocities for 1998 shown in Figure 2, the recommended velocity is V = 11.32 ft/s. The cross sectional area of the pipe, S, is calculated as

$$S = Q/V = 0.557/11.32 = 0.0492 \text{ ft}^2$$

This cross section is reasonably close to that of a 3-in dia., stainless-steel Schedule-40 pipe.

However, using the set of fluid velocities for 2008 shown in Figure 2, the recommended velocity value is signifi-

GENERAUX EQUATION

$$V = \frac{4}{\pi D^2}\left\{\frac{D^{4.84+n} nXE\left(1+F\right)\left[Z+\left(a+b\right)\left(1-\Phi\right)\right]}{\left(1+0.794Le'D\right)\left(0.000189YK\rho^{0.84}\mu^{0.16}\right)\left[\left(1+M\right)\left(1-\Phi\right)+\frac{ZM}{\left(a'+b'\right)}\right]}\right\}^{\frac{1}{2.84}}$$

Nomenclature

- ***a*** Fractional annual depreciation on pipeline, dimensionless
- ***b*** Fractional annual maintenance on pipeline, dimensionless
- ***a′*** Fractional annual depreciation on pumping installation, dimensionless
- ***b′*** Fractional annual maintenance on installation, dimensionless
- ***C*** Installed cost of pipeline, including fittings, \$/ft
- ***D*** Inside pipe diameter, ft
- ***E*** Combined fractional efficiency of pump and motor, dimensionless
- ***F*** Factor for installation and fitting, dimensionless
- ***K*** Energy cost delivered to the motor, \$/kWh
- ***Le′*** Factor for friction in fitting, equivalent length in pipe diameter per length of pipe, 1/ft
- ***M*** $= \frac{(a'+b')\cdot(E\cdot P)}{(17.9\cdot K\cdot Y)}$ Factor to express cost of piping installation, in terms of yearly cost of power delivered to the fluid, dimensionless
- ***n*** Exponent in pipe–cost equation ($C = XD^n$), dimensionless
- ***P*** Installation cost of pump and motor, \$/hp
- ***Q*** Fluid flow, ft^3/s
- ***S*** Cross sectional area, ft^2
- ***V*** Velocity, ft/s
- ***X*** Cost of 1 ft of 1-ft-dia. pipe, \$
- ***Y*** Days of operation per year (at 24 h/d)
- ***Z*** Fractional rate of return of incremental investment, dimensionless
- **Φ** Factor for taxes and other expenses, dimensionless
- **ρ** Flow density, lb/ft^3
- **μ** Fluid viscosity, cP

cantly lower V = 6.23 ft/s, calculating the cross-sectional area of the pipe $S = Q/V = 0.0894$ ft^2. This cross section is closer to a 4-in.-dia. stainless-steel Schedule-40 pipe. A larger pipe diameter is justified with the updated lower recommended velocities.

Sample calculation No. 2

For this case let us use a pipeline for the following conditions:

- Pipe: carbon steel
- Flow: Q = 250 gal/min = 0.557 ft^3/s
- Liquid: water at 60°F
- Density: ρ = 62.4 lb/ft^3

Once again, using the graph of fluid velocities for 1998 (Figure 2), the recommended velocity is V = 8 ft/s. The cross-sectional area of the pipe is $S = Q/V = 0.0696$ ft^2. This cross section is reasonably close to that of a 3.5-in.-dia., carbon-steel Schedule-40 pipe.

However, using the set of fluid velocities for 2008 shown in Figure 2, the recommended velocity value is lower, V = 4.1 ft/s, and the cross sectional area of the pipe is $S = Q/V = 0.136$ ft^2. This cross-section is closer to a 5-in.-dia., carbon-steel Schedule-40 pipe. As found in the first example calculation above, a larger pipe diameter is justified with the updated, lower recommended fluid velocities.

Conclusions

Revised values for the recommended fluid velocities as given in this article have proven to be highly sensitive to energy and material costs. However between both factors, energy cost has more significance in the total cost than material cost. It is important to remember that these costs vary depending on the inflationary surge at the current time, and so do the economic fluid velocities. In general terms, recommended velocities in fluids have decreased between 40 and 50% since 1998. ■

Edited by Gerald Ondrey

References

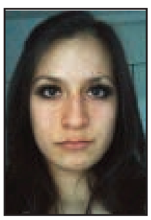
1. Perry R. H. and Chilton. C.H. "Chemical Engineer's Handbook," 5th Edition. pp. 5–30 McGraw-Hill, New York, 1973.
2. Anaya Durand A., and others, Updated Rules for Pipe Sizing, *Chem. Eng.* May 1999, pp. 153–156.
3. Marshall and Swift Equipment Cost Index. *Chem. Eng.* September 2008, p. 76, and similarly in all issues back to 1998.

Authors

Alejandro Anaya Durand (Parque España No. 15b Col. Condesa, C.P. 06140, Mexico, D.F. Email aanayadurand@hotmail.com) is a professor of chemical engineering at the National University of Mexico (UNAM), and has over 48 years experience in project and process engineering. He retired from Instituto Mexicano del Petroleo in 1998 after holding top positions. For 43 years he has been an educator in chemical engineering in several universities in Mexico, and presently he is also a consultant at several engineering companies. He has published over 250 papers related to engineering and education; is a Fellow of the AIChE; a member of National Academy of Engineering; and has received numerous chemical engineering awards Mexico. He holds a M.S. in project engineering from UNAM.

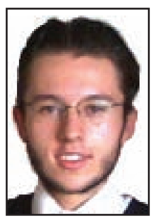
Maria Jose de Villafranca Casas (2da Cda de Tantoco #4 Frac. La Presilla Col. M. Contreras, México, D.F.; Phone: 52 55 56 52 42 14; Email: mjdevillafrancacasas@hotmail.com) is a fifth-semester chemical engineering honor student at UNAM. She is an active member of IMIQ and works as an intern at CMM (Mario Molina Center for Strategic Studies in Energy and the Environment).

Adriana Shunashi García Cornejo (1era Cda Ezequiel Ordoñez No. 14 Col. Copilco El Alto, C.P. 06340, Coyoacán, México, D.F., México; Phone: 52 55 18 70 76 40; Email: janaya_20@hotmail.com) is a fifth-semester chemical engineering honor student at UNAM. She is an active member of IMIQ.

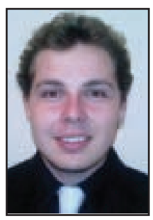


Daniela Jara Carranza (Escultores No. 42 Col. Cd Satélite, C.P 01021, Naucalpan de Juarez, Estado de México, México; Phone: 52 55 36 60 15 58; Email: aikasan2001@gmail.com) is a fifth-semester chemical engineering honor student at UNAM. She is an active member of IMIQ.

Francisco Javier Pacheco Román (Avenida Universidad 2014, Col. Copilco, c.p. 04350, Coyoacán, México, D.F. , México; Phone: 52 55 33 73 87 27; Email: erev_20@hotmail.com) is a fifth-semester chemical engineering honor student at UNAM. He is an active member of IMIQ.



Ricardo Gabriel Suárez Suárez (Industria 6, Col. Florida c.p.01030, Álvaro Obregón, México, D.F., México; Phone: 52 55 40 80 96 9; Email: gabosuarez88@gmail.com) is a fifth-semester chemical engineering honor student at UNAM. He is vice president of the UNAM student section of IMIQ.



Juan Sampieri Espinoza (Avenida Universidad 2014, Col. Copilco, c.p. 04350, Coyoacán, México, D.F., México; Phone: 52 40 13 41 51; Email: giovse_19@hotmail.com) is a fifth-semester chemical engineering honor student at UNAM. He is an active member of IMIQ.

Luis Francisco Villalobos Vazquez de la Parra (Rincon de los Arcos 95, Col. Bosque Residencial del Sur, c.p. 16010, Xochimilco, Mexico, D.F.,Mexico; Phone: 52 55 29 09 52 02; Email: luisfranciscovillalobos@gmail.com) is a fifth-semester chemical engineering honor student at UNAM. He is an active member of IMIQ.

A 'Sound' Solution to Material Flow Problems

Audiosonic acoustic cleaners use high-energy, low-frequency sound waves to eliminate particulate buildup, without damaging equipment

Donald F. Cameron
Primasonics International Ltd.

FIGURE 1. AACs are offered in a wide variety of sizes. Larger models are offered in either straight or curved designs

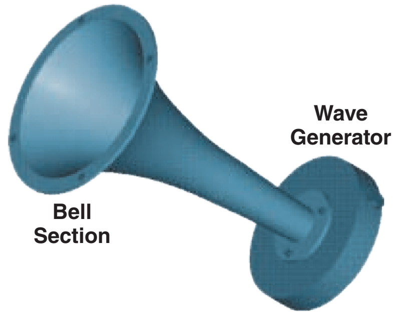


FIGURE 2. An AAC consists of a wave generator and a bell section. The wave generator creates the so-called base tone, and the variety of bell sections amplify and convert it into a particular fundamental frequency (60–420 Hz)

Particulate buildup and other material flow problems are common hurdles wherever dry materials find application in the chemical process industries (CPI). Since manual intervention is costly in terms of downtime, and can be quite hazardous for the personnel involved, dedicated equipment is an attractive way to either prevent or remove flow blockages. Equipment options include vibrators and air cannons and a lesser-known, yet sound solution known as audiosonic acoustic cleaners (AACs).

About AACs

AACs employ high-energy, low-frequency sound waves to eliminate particulate buildup and facilitate maximum material flow. Also known as sonic horns (Figure 1), these pneumatically operated devices generally produce sound waves within the 60–420 Hz frequency range.

AACs are non-intrusive, and can be employed wherever ash, dust, powders or granular materials are processed, generated, stored or transported. Reasons for installation generally echo the CPI's top priorities:

Safety: Avoid the necessity for personnel to enter process equipment by providing constant, safe, remote cleaning.

Environment: Reduce opacity spiking by employing acoustic cleaners in place of harsher mechanical systems in electrostatic precipitators, filters and so on.

Productivity: Maintain material flow and prevent blockages in many process and storage areas.

Efficiency: Provide an effective, low-cost solution that maximizes process efficiency throughout the plant.

Reliability: Minimize kiln stoppages and increase mean time between failures by preventing up- and down-stream blockages in fans and other units.

Output: Aid constant material flow and prevent blockages from occurring in a wide range of plant sectors, from blending right through to storage.

Quality: Improve blending accuracy, reduce cross-contamination and maximize bulk storage by keeping the product fresh.

Design basics, considerations

Simply put, AACs employ sound waves to prevent and eliminate flow problems. To understand how AACs work, it is first important to consider some fundamentals of sound. Sound can be described as the passage of very rapid pressure fluctuations through a medium by means of a vibrating force. The human ear does not actually hear sound but uses a pressure sensitive mechanism to detect very-rapid pressure fluctuations. The creation of sound simply requires two things: a vibrating source and a transmission medium.

An acoustical sound energy level, also known as a sound pressure level (SPL) is normally measured in a decibel (dB), which is a logarithmic unit. Generally speaking AACs have an energy level around 150 dB. It is this sound energy that is absorbed into the bonded material causing a series of very rapid pressure fluctuations, which result in the instant debonding of the material particles — both from themselves and from any surface.

AACs are extremely simple in their operation, only requiring a plant's standard compressed-air supply for the energy source. Compressed air enters the wave generator and forces the only moving part, an ultra high-grade titanium diaphragm, to oscillate very rapidly within its specially designed housing. These rapid oscillations create the base tone, and the different bell sections convert, amplify and distribute the base tone into a range of selected, key fundamental frequencies (Figure 2).

A periodic "sounding" (typically 5–10 s every 10–60 min) is all that is required to achieve the desired goal. Larger models are usually available either in straight or curved styles.

Specific design considerations involve the wave generator (the vibrating source), the bell section (the transmission medium) and the frequency.

The wave generator. The wave generator usually contains a titanium diaphragm clamped within the wave generator body. Compressed air, applied for a few seconds at periodic intervals, produces a base tone. This base tone is then amplified by the bell section and transmitted to a particular fundamental frequency in relation to the bell section design and length.

The bell section. The shape of the bell section is also a very important design factor, as the sound transmission and radiation from the bell section of

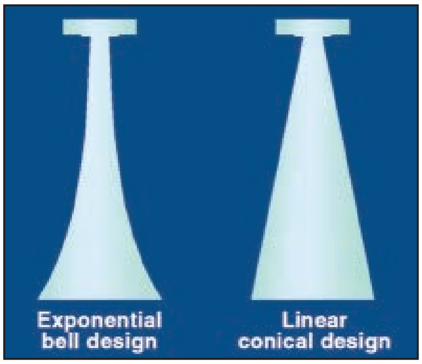


FIGURE 3. For a given length and end area of a bell section, an exponential shape (left) will always transmit greater acoustic power at all frequencies above the critical value than a conical shape (right)

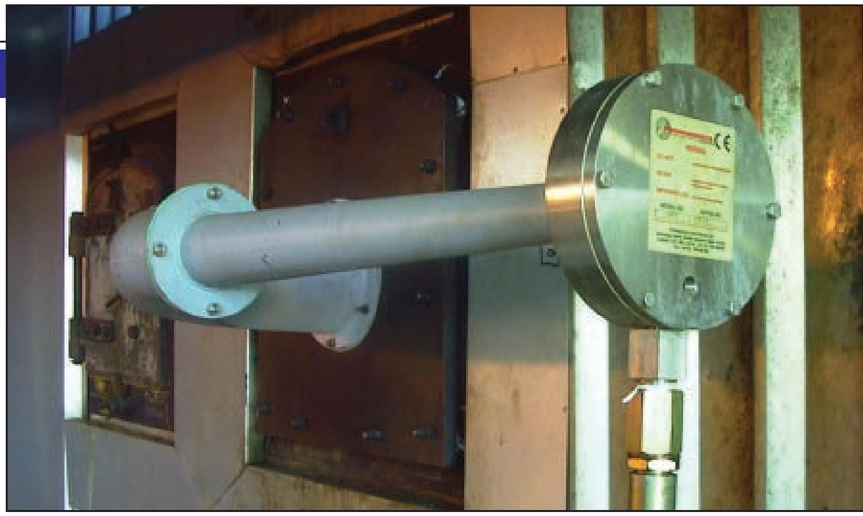


FIGURE 4. AACs are non-intrusive, and can be employed wherever dry materials are processed, generated, stored or transported. A periodic "sounding" (typically 5–10 s every 10–60 min) is all that is required to achieve the desired goal

changing cross-section is greatly influenced by the manner in which the sections change, plus the physical length of the bell section itself. For a given length and end area, an exponential bell shape (Figure 3, left), for instance, will always transmit greater acoustic power at all frequencies above the critical value than a linear conical bell shape (Figure 3, right).

Specifying frequency. Sound waves with differing fundamental frequencies have significantly different power ranges and cleaning effects. Due to the velocity or speed of sound in AACs, the following relationships apply:

- The higher the frequency, the shorter the wavelength path. This translates into high-intensity, localized cleaning power (1–10 m)
- At very short wave lengths (high frequency, say 420 Hz) interference occurs, and the sound distribution becomes beam like so that only points that lie in the region of a line coaxial with the centerline of the bell section will experience high power effective cleaning. This is why models that operate at the higher end of the frequency range are most effective at aiding material flow at the discharge point of silos and hoppers
- The lower the frequency, the longer the wavelength path. This translates into powerful long-distance, deep-penetrating cleaning power (20–50 m)
- At large wavelengths (low frequency, say 60 or 75 Hz) the sound will be transmitted in the form of a spherical wave, and points equidistant from the exit of the bell section will experience similar sound energy levels. This is why models that operate at the lower end of the frequency range are most effective at preventing material blockage in large vessels such as silos

AACs versus alternatives

It is important to note and understand several main advantages that AACs have over alternative methods that have been employed within various dry materials applications.

AACs don't damage equipment. AACs operate at frequencies very much higher than the resonance frequency of typical materials of construction such as steel, ceramic lining and concrete. Therefore they do not cause any vibrational damage to vessels or structures because their sonic debonding power is directly absorbed into the process material and is not absorbed into the structure in any damaging manner. The results of numerous trials using AACs within silos and metal structures are available to prove this.

AACs versus vibrators. Vibrators, on the other hand, by their very nature and method of installation cause vibration and stress weaknesses within the vessel or structure to which they are attached. The vibration resonances first have to pass through the vessel wall before reaching the material.

AACs versus air cannons. Air cannons and blasters seek to affect a very localized cure for a blockage problem that has already occurred. In many cases the air cannon simply blows a localized hole through the blockage, necessitating the installation of many air cannons within the general problem area. It is generally true to say that one very rarely finds a single air cannon in effective operation.

AACs, in contrast, prevent the buildup and blockages from occurring in the first place by constantly debonding the material from the vessel or structure surface. Secondly, unlike air cannons, which are unidirectional, sound waves travel at an exceptionally fast speed (344 m/s at normal temperature and pressure) in a wide radius. Furthermore they bounce off all surfaces and rebound back onto other surfaces.

Typical applications

AACs find use in a wide variety of applications. Below is a list of them, followed by descriptions of some of the most common:

- Silos and hoppers
- Electrostatic precipitators (ESPs) and filters
- Boilers
- Air heaters
- Superheaters
- Economizers
- Cyclones
- Dryers
- Coolers
- Mixers
- Reactor vessels
- Calciners
- Induced draft fans
- Air classifiers
- Mills
- Ductwork

Silos and hoppers. Material bridging across silo or hopper outlets causes restricted flow or no flow, leading to so-called hammer rash, a result of manual efforts to dislodge blockages

HOW AUDIOSONICS COMPARE WITH OTHER ACOUSTIC TECHNOLOGIES

In ultrasonics, the sound extends beyond human hearing at the higher 20-kHz end of the frequency range. Ultrasonic cleaners, for instance, operate at frequencies between 25 and 80 kHz. Their application typically involves a liquid media for total cleaning of components and other liquid environment buildups.

In infrasonics, the sound waves are very powerful. Infrasonic acoustic cleaners are inaudible and operate between 11 and 22 kHz. They are mainly employed in the following situations:

- Where there is limited access into an industrial boiler, for example
- Where the area to be cleaned has a very large volume
- Where there is high restriction on noise level

Great care must be taken with these applications so as not to set up damaging resonance within the structure itself.

Audiosonics, in contrast, operate generally within the 60–420 Hz frequency range. ❑

by hitting the side of the unit. In such cases, maximum, continuous flow can be achieved by the introduction of a high frequency acoustic cleaner.

Another typical problem in silos and hoppers is ratholing, whereby material buildup on the side walls of a silo results from funnel flow and greatly reduces silo capacity. While ratholing is a very common problem, it is also one of the easiest to solve with the introduction of an AAC.

Baghouse filters and ESPs. AACs can be implemented to help filters with both bag blockage and hopper pluggage. AACs can deal effectively with very large filter or ESP applications. On a large reverse-jet filter, for instance, AACs were installed on each of 12 hoppers to prevent bridging and ash flow and eliminate opacity spiking at a smelting plant. Meanwhile, on an ESP application, the installation of an AAC enabled the end user to cease operating the mechanical rapping system completely.

Boilers. AACs prevent ash from building up and baking onto boiler tubes, thereby eliminating harsh or manual cleaning regimes and improving thermal efficiency.

Air heaters. AACs even find application in air heaters, such as in ethylene cracking towers, where AACs prevent the build up of fine ash. ■

Edited by Rebekkah Marshall

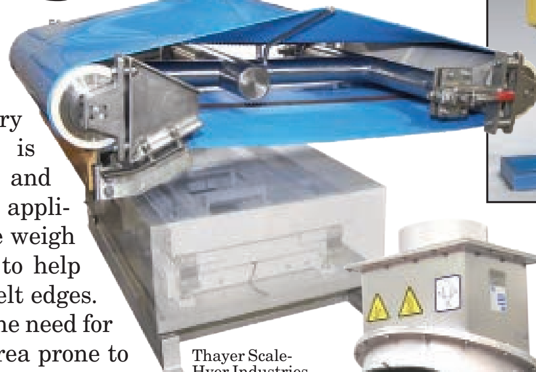
Author

Donald F. Cameron is managing director of Primasonics International Ltd. (Technology Centre, Gilwilly Estate, Penrith, Cumbria, CA11 9BD, U.K.;Phone:+44-1768-866648; Email: don@primasonics.com; Website: www.primasonics.com). He has over 35 years experience in a wide range of process industries with particular disciplines in chemical engineering and food science. During his career Cameron has designed and built factories in Canada, China, Iceland, Spain and Africa as well as within the U.K. Faced with a range of material flow problems throughout his career, his ambition was to find an affordable innovative and simple solution to prevent material blockages and build up and improve material flow. In the last twelve years he has developed Primasonics International into being the leading specialist designer and manufacturer of acoustic cleaners.

Flexicon

FOCUS ON

Weighing



Thayer Scale-Hyer Industries

This weigh belt helps minimize material build up

The Model SI Ultra-Sanitary Insertion weigh belt (photo) is designed to enable effective and efficient cleaning for sanitary applications in food processing. The weigh belt features a trough shape to help keep product away from the belt edges. The trough shape eliminates the need for side skirts, which can be an area prone to material build-up. The entire conveyor assembly of the insertion weigh belt is coupled to a patented, mass counter-balanced force-measurement suspension system (FMSS) that allows load-cell selection based on net-, rather than gross-weighing requirements. The Model SI is built to exceed U.S. Department of Agriculture standards for cheese, dairy, meat, poultry, confectionary, baked goods, prepared foods and more. — *Thayer Scale-Hyer Industries Inc., Pembroke, Mass.*
www.thayerscale.com

K-Tron

Measure bulk material flows with no moving parts

The Smart FlowMeter (photo) is used for in line weighing applications in processes requiring reliable metering and registering of bulk material flows. Based on Newtonian physics principles, the Smart FlowMeter is capable of measuring granules, chips and fibers. As the bulk solid flows through two force-sensor stations with no moving parts, the mass is measured as the bulk material acts perpendicularly on an inclined chute that is mounted on a force transducer. The bulk material then flows into a lower, vertically oriented channel where the acceleration rate is determined. The signals from the two sensors are used to calculate material flowrate per unit time. — *K-Tron Ltd., Niederlenz, Switzerland*
www.ktron.com

Mettler Toledo International

This scale is suitable for potentially hazardous areas

The IND560x (photo) is specifically designed for process control and manual weighing operations in Division 1 or Zone 1/21 hazardous areas. It contains analog or electromagnetic force restoration (EMFR) weighing technologies, and features a highly configurable operator interface with numerous programmable, on-screen prompts. The graphic display shows weighing transaction status clearly, helping to reduce errors. In filling and dosing applications, the instrument's target update rate of 50 Hz allows process controls to be triggered in 20 ms. The scale instrument is coupled with the ACM500, a communications accessory module that provides bidirectional communication between the weighing terminal and a larger automation system, such as a programmable logic controller (PLC) or a distributed control system (DCS). The ACM500 and IND560x can be connected using either a copper-wire-carried current loop signal or a fiber optic connection. The ACM500 allows the IND560x to communicate with several devices using multiple protocols simultaneously. — *Mettler Toledo International Inc., Solon, Ohio*
www.mt.com

This weigh batch system can loosen bulk material before blending

A new bag-weigh-batch system can loosen bulk solid material that has solidified during storage and shipment before discharging the material by weight and blending it into a liquid stream. The skid-mounted system (photo) incorporates two bulk-bag unloading frames, each with an integral bulk bag conditioner comprised of a hydraulic pump and two rams with contoured end plates that press opposing sides of bulk bags. The unloaders' cantilevered hoists and motorized trolleys allow conditioning of bulk bags at various heights, as well as loading and unloading of bags without the need for a forklift. Safety interlocks prevent operation of the conditioner when the unloaders' doors are open. The unloaders also feature a Spout-Lock clamp ring that forms a high-integrity seal between the clean side of the bag spout and the clean side of the equipment, while a Tele-Tube telescoping tube maintains constant downward pressure on the clamp ring and bag spout, elongating the bag as it empties to promote complete discharge. — *Flexicon Corp., Bethlehem, Pa.*
www.flexicon.com

Handle eight load cells with this crane-weighing system

Applicable to new and existing cranes, this crane-weighing system features G4 advanced process-control software that can connect up to eight load cells, each with a separate channel, while performing standard weighing functions and controlling and logging overload. The weighing solution includes double-ended, shear-beam load cells with I-beam cross sections, and collects data on weight, time and engine running

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

Hardy Instruments

hours, which enables better crane security and safety. The software optimizes service and maintenance intervals to help reduce costs. It also sets values for up to 32 load levels, logs up to three different operation times, compensates for faulty load cells, enables data downloading onto memory sticks, and enables communication via field bus or analog output. — *Vishay Intertechnology, Inc., Malvern, Pa.*
www.vishay.com

Use this network interface for fast transfer of time-critical information

The HI 4050 (photo), a general-purpose weight controller used in vessel-weighing, force-measurement, filling, level-by-weight, and batching/blending applications, is now available with a ControlNet network interface. The new interface allows rapid transfer of time-critical information at rates of 5 Mb/sec in a redundant, deterministic and predictable manner. Also, information can be transmitted to up to 98 additional nodes at distances of 250 m to 5 km. The interface comes with two BNC (Bayonet Neill Concelman) connectors for cable redundancy, but can operate with a single or dual RG-6 coaxial cable bus. The HI 4050 is available with a.c. or d.c. power, as well as in-panel, wall, remote or blind-DIN rail-mounting packaging configurations. — *Hardy Instruments, San Diego, Calif.*
www.hardyinstruments.com

Handle a wide range of feed rates with this weigh feeder

This continuous loss-in-weight feeder is capable of handling feedrates between 20 and 24,000 lb/h with accuracies of 0.25 to 1.0% on a minute-to-minute basis to two standard deviations. The weigh feeder is controlled by a microprocessor-based system equipped with one million counts of resolution and exclusive disturbance elimination technology. The continuous weighing feeding devices can include pan or tube feeders, screw feeders and belt feeders. The weigh feeder system electronically balances tare weight so the controller senses only the weight of the material in the supply hoppers. — *VibraScrew Inc., Totowa, N.J.*
www.vibrascrew.com

Use this batching feeder for food flavorings

The FlexWall loss-in-weight batching feeder (photo) is designed for use in applying snack food flavorings, including onsite movie-theater popcorn. After mixing, the flavorings are transferred, either manually or in an automated process, into a bulk bag that is emptied into the weigh hopper. The system can handle poor-flowing ingredients such as butter. — *Brabender Technologie Inc., Mississauga, Ont.*
www.brabenderti.com ■

Scott Jenkins

PRODUCT SHOWCASE

SOFTWARE

NEW & USED EQUIPMENT

Advertisers' Index

- • International Section
- * Additional information in 2010 Buyers' Guide

CHEMICAL ENGINEERING New Product Information

January 2010

JustFAXit! or go to www.che.com/adlinks

Fill out the form and circle or write in the number(s) below, cut it out, and fax it to 800-571-7730.

Go on the Web and fill out the online reader service card.

Name ______________________ Title ______________________

Company ______________________

Address ______________________

City ____________ State/Province ____________ Zip/Postal Code ____________

Country\ ____________ Telephone ____________ Fax ____________

Email | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

FREE PRODUCT INFO

(please answer all the questions)

YOUR INDUSTRY

01 Food & Beverages
02 Wood, Pulp & Paper
03 Inorganic Chemicals
04 Plastics, Synthetic Resins
05 Drugs & Cosmetics
06 Soaps & Detergents
07 Paints & Allied Products
08 Organic Chemicals
09 Agricultural Chemicals
10 Petroleum Refining, Coal Products
11 Rubber & Misc. Plastics
12 Stone, Clay, Glass, Ceramics
13 Metallurgical & Metal Products
14 Engineering, Design & Construction Firms
15 Engineering/Environmental Services
16 Equipment Manufacturer
17 Energy incl. Co-generation
18 Other____________

JOB FUNCTION

20 Corporate Management
21 Plant Operations incl. Maintenance
22 Engineering
23 Research & Development
24 Safety & Environmental
26 Other____________

EMPLOYEE SIZE

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

YOU RECOMMEND, SPECIFY, PURCHASE

(please circle all that apply)

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

1	16	31	46	61	76	91	106	121	136	151	166	181	196	211	226	241	256	271	286	301	316	331	346	361	376	391	406	421	436	451	466	481	496	511	526	541	556	571	586
2	17	32	47	62	77	92	107	122	137	152	167	182	197	212	227	242	257	272	287	302	317	332	347	362	377	392	407	422	437	452	467	482	497	512	527	542	557	572	587
3	18	33	48	63	78	93	108	123	138	153	168	183	198	213	228	243	258	273	288	303	318	333	348	363	378	393	408	423	438	453	468	483	498	513	528	543	558	573	588
4	19	34	49	64	79	94	109	124	139	154	169	184	199	214	229	244	259	274	289	304	319	334	349	364	379	394	409	424	439	454	469	484	499	514	529	544	559	574	589
5	20	35	50	65	80	95	110	125	140	155	170	185	200	215	230	245	260	275	290	305	320	335	350	365	380	395	410	425	440	455	470	485	500	515	530	545	560	575	590
6	21	36	51	66	81	96	111	126	141	156	171	186	201	216	231	246	261	276	291	306	321	336	351	366	381	396	411	426	441	456	471	486	501	516	531	546	561	576	591
7	22	37	52	67	82	97	112	127	142	157	172	187	202	217	232	247	262	277	292	307	322	337	352	367	382	397	412	427	442	457	472	487	502	517	532	547	562	577	592
8	23	38	53	68	83	98	113	128	143	158	173	188	203	218	233	248	263	278	293	308	323	338	353	368	383	398	413	428	443	458	473	488	503	518	533	548	563	578	593
9	24	39	54	69	84	99	114	129	144	159	174	189	204	219	234	249	264	279	294	309	324	339	354	369	384	399	414	429	444	459	474	489	504	519	534	549	564	579	594
10	25	40	55	70	85	100	115	130	145	160	175	190	205	220	235	250	265	280	295	310	325	340	355	370	385	400	415	430	445	460	475	490	505	520	535	550	565	580	595
11	26	41	56	71	86	101	116	131	146	161	176	191	206	221	236	251	266	281	296	311	326	341	356	371	386	401	416	431	446	461	476	491	506	521	536	551	566	581	596
12	27	42	57	72	87	102	117	132	147	162	177	192	207	222	237	252	267	282	297	312	327	342	357	372	387	402	417	432	447	462	477	492	507	522	537	552	567	582	597
13	28	43	58	73	88	103	118	133	148	163	178	193	208	223	238	253	268	283	298	313	328	343	358	373	388	403	418	433	448	463	478	493	508	523	538	553	568	583	598
14	29	44	59	74	89	104	119	134	149	164	179	194	209	224	239	254	269	284	299	314	329	344	359	374	389	404	419	434	449	464	479	494	509	524	539	554	569	584	599
15	30	45	60	75	90	105	120	135	150	165	180	195	210	225	240	255	270	285	300	315	330	345	360	375	390	405	420	435	450	465	480	495	510	525	540	555	570	585	600

If number(s) do not appear above, please write them here and circle: ____________

Fax this page back to 800-571-7730

ADVERTISING SALES REPRESENTATIVES

Mike O'Rourke, Publisher
Chemical Engineering
110 William St., New York, NY 10038-3901
Tel: 215-340-1366; Fax: 609-482-4146
E-mail: morourke@che.com
Alabama, Canada, Connecticut, Delaware, Florida, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York (minus Western New York), North & South Carolina, Pennsylvania (minus Western Pennsylvania), Rhode Island, Tennessee, Vermont, Virginia, Washington, D.C., West Virginia, Latin America

North America

Jason Bullock,
District Sales Manager
Chemical Engineering
8325 Broadway, Ste. 202/PMB 261
Pearland, TX 77581
Tel: 281-485-4077; Fax: 281-485-1285
E-mail: jbullock@che.com;
Arkansas, Arizona, California, Colorado, Georgia, Kansas, Louisiana, Missouri, Nevada, Oklahoma, Texas

George Gortz,
District Sales Manager
Chemical Engineering
2612 Edgerton Road
University Heights, OH 44118
Tel: 216-932-2700; Fax 216-932-5810
E-mail: ggortz@che.com
Indiana, Illinois, Iowa, Kentucky, Michigan, Minnesota, Ohio, Western New York, Western Pennsylvania, Wisconsin

Helene Hicks,
Inside Sales Manager
Chemical Engineering;
110 William St., New York, NY 10038-3901
Tel: 212-621-4958; Fax: 212-621-4976;
E-mail: hhicks@che.com
Product Showcase, Literature Reviews, Classified Display Advertising
Alaska, Hawaii, Idaho, Mississippi, Montana, Nebraska, New Mexico, North & South Dakota, Oregon, Utah, Washington, Wyoming

International

Petra Trautes
Chemical Engineering
Zeilweg 44
D-60439 Frankfurt am Main
Germany
Phone: +49-69-2547-2073
Fax: +49-69-5700-2484
Email: ptrautes@che.com
Austria, Czech Republic, Benelux, Eastern Europe, Germany, Scandinavia, Switzerland, United Kingdom

Dipali Dhar
Chemical Engineering
110 William St., New York, NY 10038-3901
Tel: 212-621-4919; Fax: 212-621-4990
E-mail: ddhar@chemweek.com
India

Katshuhiro Ishii
Chemical Engineering
Ace Media Service Inc., 12-6, 4-chome
Nishiiko, Adachi-ku, Tokyo 121, Japan
Tel: 81-3-5691-3335; Fax: 81-3-5691-3336
E-mail: amskatsu@dream.com
Japan

Ferruccio Silvera
Chemical Engineering
Silvera Pubblicita
Viale Monza, 24 Milano 20127, Italy
Tel: 39-02-284-6716; Fax: 39-02-289-3849
E-mail: ferruccio@silvera.it/www.silvera.it
Andorra, France, Gibraltar, Greece, Israel, Italy, Portugal, Spain

Rudy Teng
Chemical Engineering
Professional Publication Agency
6F-3 # 103 Fen Liau St Neihu
Taipei 114 Taiwan
Tel: 886-2-2799-3110 ext 330;
Fax: 886-2-2799-5560
E-mail: rudy_teng@ppa.com.tw
or idpt808@seed.net.tw
Asia-Pacific, Hong Kong, People's Republic of China, Taiwan

BUSINESS NEWS

PLANT WATCH

Borealis invests in semi-commercial catalyst plant

December 14, 2009 — Borealis (Vienna, Austria; www.borealisgroup.com) has announced plans for a €75-million investment in Linz, Austria for a new semi-commercial catalyst plant to develop and scale up new catalysts for the production of innovative new polymers. Borealis has developed a revolutionary, new production technology for catalysts that is protected by 47 international patents. Based on this production technology, the new catalyst plant will support research in the areas of catalyst development and will further improve processes for catalyst production. The investment in a semi-commercial plant for catalysts in Linz allows Borealis to undertake the necessary development work as well as produce semi-commercial batches for the first phase in the development process. This requires a close alignment with the new, recently commissioned Borstar pilot plant in Schwechat, which involved an investment of € 30 million.

Toyo is awarded a methionine project in China

December 14, 2009 — Toyo Engineering Corp. (Tokyo; www.toyo-eng.co.jp) has been awarded a project for methionine production facilities that will be constructed by Sumitomo Chemical Co. and Dalian Jingang Group Co. in the Dalian Economic and Technological Development Zone in China. The facilities will produce 20,000 ton/yr of methionine, a nutritive feed additive. Construction of the plant is scheduled to commence in the spring of 2010.

GEA lands an order for a milk plant in Australia

December 10, 2009 — The Process Technology Segment of GEA Group AG (Bochum, Germany; www.geagroup.com) has received an order for a complete milk-powder factory. The customer is the Australian Dairy Group, Burra Foods. The total order is in excess of €23 million and includes engineering, manufacturing, supply, installation and commissioning of the plant. The plant is expected to be completed in August 2010.

Perstorp to increase isocyanates production capacity in China

November 18, 2009 — Specialty chemicals company Perstorp (Perstorp, Sweden; www.perstorp.com) plans to increase its production of aliphatic polyisocyanates in response to growing market demand in Asia and China in particular. The increased production capacity will reach 12,000 m.t./yr and is expected to commence in 2012. In parallel, Perstorp plans to debottleneck existing plants to support growth outside Asia.

CB&I wins a petroleum refinery project in Colombia

November 18, 2009 — CB&I (Houston; www.cbi.com) has been awarded a project valued in excess of $1.4 billion by Refinería de Cartagena S.A. (Reficar) for the engineering, procurement services and construction of a new petroleum refinery, with processing capacity of 165,000 bbl/d, adjacent to Reficar's refinery in Cartagena, Colombia. CB&I's scope also includes revamping the existing 80,000-bbl/d refinery. The overall project will enable Reficar to produce clean, ultra-low sulfur gasoline and diesel from heavy crude. The project is scheduled for completion in 2012.

SABIC and Danieli plan construction of new steel plant

November 16, 2009 — Saudi Basic Industries Corp. (SABIC; Riyadh, Saudi Arabia; www.sabic.com) has announced that its manufacturing affiliate, Saudi Iron and Steel Co. (HADEED), signed an agreement with the Italian company, Danieli, for the construction of a steel plant and a production line for galvanizing long products in Jubail, Saudi Arabia. The new plant, which is scheduled to start up in the second half of 2012, will have a production capacity of 1-million ton/yr of steel billets. It will increase the total production capacity of HADEED to 6-million ton/yr, of which long products will account for 4-million ton/yr.

Pörner Group to build a new Biturox plant in Morocco

November 12, 2009 — A contract between the Moroccan refining company, Samir, and the Austrian engineering company, Pörner Ingenieurgesellschaft mbH (Vienna, Austria; www.poerner.at) for the planning and construction of a new Biturox plant for the production of bitumen, has been finalized and signed. The plant will have a production capacity of 270,000 ton/yr of road-making bitumen. Following the project start in January 2010, the plant will be completed and handed over to Samir by summer 2011.

MERGERS AND ACQUISITIONS

Dow forms a new company called Pfenex Inc.

December 7, 2009 — The Dow Chemical Company (Dow; Midland, Mich.; www.dow.com) has formed a new independent company that will be known as Pfenex Inc. through its Dow Venture Capital group. The new company, headquartered in San Diego, Calif., is based on human-health applications of a Dow-developed technology called Pfenex Expression Technology, a Pseudomonas fluorescens-based platform that uses high throughput, parallel processing methodologies for optimized protein production. Dow will hold a significant minority stake in Pfenex along with Signet Healthcare Partners, an experienced venture-capital investor focused on the healthcare sector. Financial terms are not being disclosed.

AkzoNobel acquires Australian specialty starch activities

November 23, 2009 — AkzoNobel's (Amsterdam; www.akzonobel.com) National Starch has agreed to acquire Penford Australia Ltd.'s specialty grain wet-milling and manufacturing facility in Lane Cove. The deal also includes certain other intellectual property and assets of Penford's Australian specialty starch business. Financial details were not disclosed. Final closure of the deal was expected by the end of 2009.

AkzoNobel to acquire Dow powder coatings activities

November 12, 2009 — AkzoNobel has signed an agreement with The Dow Chemical Company (Dow) to acquire its powder coatings activities. The powder coatings activities were purchased by Dow earlier in 2009 as part of its acquisition of Rohm & Haas. This business achieves global sales of several hundred million dollars. The transaction is expected to close during the second quarter of 2010, subject to customary closing conditions, including regulatory approvals. Financial details were not disclosed. ■

Dorothy Lozowski

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

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

January 2010; VOL. 117; NO. 1

Chemical Engineering copyright @ 2010 (ISSN 0009-2460) is published monthly, with an additional issue in October, by Access Intelligence, LLC, 4 Choke Cherry Road, 2nd Floor, Rockville, MD, 20850. Chemical Engineering Executive, Editorial, Advertising and Publication Offices: 110 William Street, 11th Floor, New York, NY 10038; Phone: 212-621-4674, Fax: 212-621-4694. Subscription rates: $59.00 U.S. and U.S. possessions, Canada, Mexico; $179 International. $20.00 Back issue & Single copy sales. Periodicals postage paid at Rockville, MD and additional mailing offices. Postmaster: Send address changes to Chemical Engineering, Fulfillment Manager, P.O. Box 3588, Northbrook, IL 60065-3588. Phone: 847-564-9290, Fax: 847-564-9453, email: clientservices@che.com. Change of address, two to eight week notice requested. For information regarding article reprints, please contact Angie Van Gorder at angie.vangorder@theygsgroup.com. Contents may not be reproduced in any form without written permission. **Publications Mail Product Sales Agreement No. PM40063731. Return undeliverable Canadian Addresses to: P.O. Box 1632, Windsor, ON N9A7C9.**

FOR MORE ECONOMIC INDICATORS, SEE NEXT PAGE

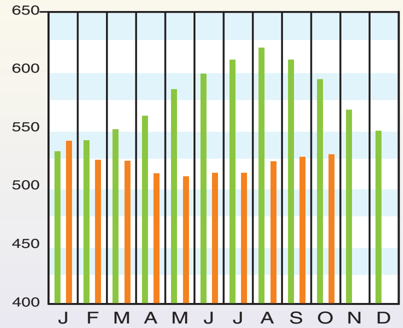
Economic Indicators

2009 ■ 2008 ■

CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957-59 = 100)	Oct.'09 Prelim.	Sep.'09 Final	Oct.'08 Final
***CE* Index**	527.9	525.7	592.2
Equipment	623.6	621.5	720.0
Heat exchangers & tanks	567.0	563.4	711.7
Process machinery	605.7	604.0	664.7
Pipe, valves & fittings	768.9	768.3	864.0
Process instruments	409.8	409.7	439.0
Pumps & compressors	896.3	895.9	893.0
Electrical equipment	464.2	464.7	471.9
Structural supports & misc	636.5	632.5	771.8
Construction labor	331.4	327.5	326.2
Buildings	495.4	493.2	522.8
Engineering & supervision	344.6	345.4	351.3

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

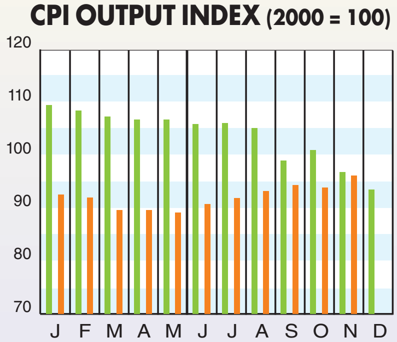


Starting with the April 2007 Final numbers, several of the data series for labor and compressors have been converted to accommodate series IDs that were discontinued by the U.S. Bureau of Labor Statistics

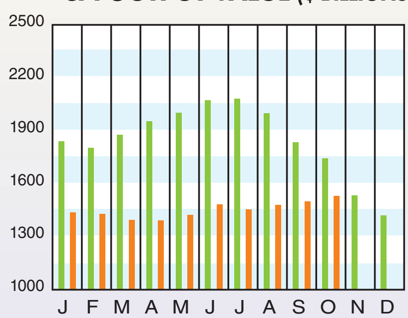
CURRENT BUSINESS INDICATORS

	LATEST		PREVIOUS				YEAR AGO	
CPI output index (2000 = 100)	Nov.'09	= 96.1	Oct.'09	= 93.9	Sep.'09	= 94.3	Nov.'08	= 96.8
CPI value of output, $ billions	Oct.'09	= 1,530.5	Sep.'09	= 1,499.6	Aug.'09	= 1,481.5	Oct.'08	= 1,744.1
CPI operating rate, %	Nov.'09	= 71.0	Oct.'09	= 69.3	Sep.'09	= 69.5	Nov.'08	= 70.5
Producer prices, industrial chemicals (1982 = 100)	Nov.'09	= 251.3	Oct.'09	= 243.3	Sep.'09	= 248.4	Nov.'08	= 246.2
Industrial Production in Manufacturing (2002=100)*	Nov.'09	= 98.6	Oct.'09	= 97.5	Sep.'09	= 97.7	Nov.'08	= 103.6
Hourly earnings index, chemical & allied products (1992 = 100)	Nov.'09	= 151.8	Oct.'09	= 150.1	Sep.'09	= 150.2	Nov.'08	= 144.3
Productivity index, chemicals & allied products (1992 = 100)	Nov.'09	= 138.6	Oct.'09	= 136.7	Sep.'09	= 136.8	Nov.'08	= 125.5

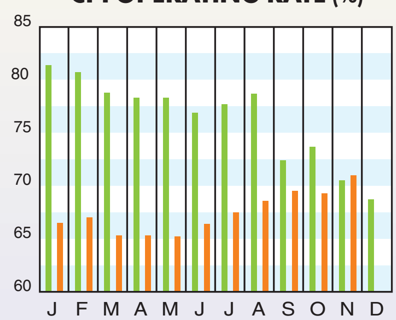
CPI OUTPUT INDEX (2000 = 100)



CPI OUTPUT VALUE ($ BILLIONS)



CPI OPERATING RATE (%)



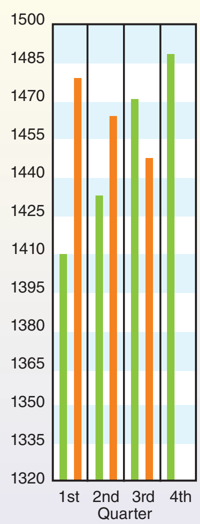
*Due to discontinuance, the Index of Industrial Activity has been replaced by the Industrial Production in Manufacturing index from the U.S. Federal Reserve Board.
Current business indicators provided by Global insight, Inc., Lexington, Mass.

MARSHALL & SWIFT EQUIPMENT COST INDEX

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

Annual Index:

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



CURRENT TRENDS

For the first time since the global recession hit the CPI in late 2008, operating rates have finally surpassed the year-over-year deficit, and CPI output is nearing the same turning point.

Meanwhile, capital equipment prices (as reflected in the *Chemical Engineering* Plant Cost Index) continue to climb. This trend is atypical for the end of a year — since equipment prices usually peak in the summer — but is an effect of demand recovery.

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