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Bioalcoholic Fuels

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Optimizing CO_2 Capture, Dehydration and Compression Facilities

The removal of CO_2 by liquid absorbents is widely implemented in the field of gas processing, chemical production, and coal gasification. Many power plants are looking at post-combustion CO_2 recovery to meet environmental regulations and to produce CO_2 for enhanced oil recovery applications. The figure below illustrates actual data of fuel consumption in 2005 and an estimate of energy demand for various fuels from 2010 to 2030. The world energy demand will likely increase at rates of 10–15% every 10 years. This increase could raise the CO_2 emissions by about 50% by 2030 as compared with the current level of CO_2 emissions. The industrial countries (North America, Western Europe and OECD Pacific) contribute to this jump in emissions by 70% compared to the rest of the world, and more than 60% of these emissions will come from power generation and industrial sectors.
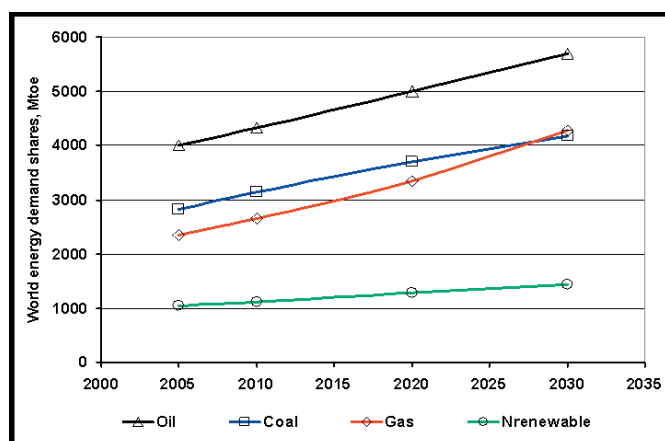
Despite the strong recommendations from certain governments, there are very few actual investments in CO_2 capture facilities geared toward reducing greenhouse gas emissions mainly because of the high cost of CO_2 recovery from flue gas. CO_2 capture costs can be minimized, however, by designing an energy efficient gas absorption process. Based on the findings of recent conceptual engineering studies, HTC Purenergy estimated the production cost to be US$ 49/ton CO_2 (US$ 54/ tonne CO_2) for 90% CO_2 recovery of 4 mole% CO_2 content in the flue gas of NGCC power plants. A separate study showed the cost for 90% CO_2 recovery of 12 mole% CO_2 from a coal fired power plant to be US$ 30/ton CO_2 (US$ 33/tonne CO_2). The cost of CO_2 recovery from coal power plant flue gas is substantially less than that of NGCC power plant flue gas due to the higher CO_2 content in the feed.

The energy efficiency of a CO_2 capture plant depends primarily on the performance of the solvent and optimization of the plant. In traditional flue gas plant designs, MEA was the primary solvent and was limited to 20 wt% to minimize equipment corrosion. Recent developments in controlling corrosion and degradation has allowed an increase in the solvent concentration to about 30 wt% thus decreasing the required circulation and subsequent steam demand. A recent DOE study shows the steam consumption for an existing CO_2 plant using 18 wt% MEA (Kerr McGee Process) is 3.45 lb of steam per lb of CO_2 for amine regeneration. A modern process that uses 30 wt% MEA is expected to use 1.67 lb of steam per lb of CO_2 for amine regeneration. The HTC formulated solvent is a proprietary blend of amines and has a lower steam usage than the conventional MEA solvent. Based on the material and energy balances for the plant designed in the recent study, the reboiler steam consumption is estimated at about 1.47 lb steam/lb CO_2 using the proposed

formulated solvent without implementing any split flow configurations. This is much less than the reported steam usage for the MEA solvent.

The design of a facility to capture 90% of the CO_2 from the flue gas of a coal fired power plant is based on the specified flue gas conditions, CO_2 product specifications, and constraints. Using the ProMax® process simulation software from Bryan Research & Engineering, CO_2 capture units can be designed and optimized for the required CO_2 recovery using a variety of amine solvents. The following figure represents a simplified process flow diagram for the proposed CO_2 Capture Plant.
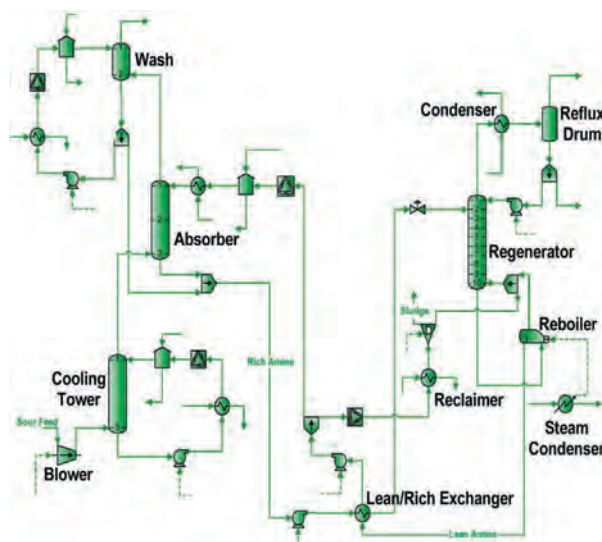
The table below presents the main findings for CO_2 capture from the coal fired power plant and the NGCC power plant, each designed to produce about 3307 ton per day (3,000 TPD metric). To produce the same capacity of CO_2, only one train with smaller column diameters is required in the case of the coal power plant and two trains with larger column diameters are required in the NGCC Power Plant case. This is mainly due to processing a larger flue gas with lower CO_2 content in the NGCC power plant. Consequently, a substantial reduction in the capital and production cost was reported for the coal fired power plant CO_2 recovery facility.

Parameter	Coal Power Plant	NGCC Power Plant
CO_2 Production Capacity, ton / day	3307	3307
CO_2 Recovery, %	90	90
CO_2 in flue gas, mol%	12	4
Number of trains	1	2
Flue gas rate, MMSCFD	528	920
Absorber diameter, ft	32.8	39.4
Regenerator diameter, ft	19.7	19.7
Capital Cost, million US$	165	227
Operating cost, million US$	25	51
Production cost, US$/ton	30	49

For more information about this study, see the full article at **www.bre.com/support/technical-articles/gas-treating.aspx**.

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Recognizing a distillation icon

On March 24, at the American Institute of Chemical Engineers' (AIChE; New York; www.aiche.org) Spring Meeting in San Antonio, Tex., the Separations Division honored the myriad contributions of Dr. Karl T. Chuang. Given the scope and impact of his contributions, we are likewise proud to recognize him here.

"Very few chemical engineers have spent as much time at as many chemical engineering frontiers as Professor Chuang," notes Michael Resetarits, technical director at Fractionation Research, Inc. (Stillwater, Okla.; fri.org) and chair of the distillation track and session in which Chuang was honored.

Chuang received his Ph.D. from the University of Alberta in 1971. "By 1986, he was quite possibly the world's foremost expert at heavy water production," says Resetarits. Chuang then joined the University of Alberta faculty, where he authored almost 200 fully refereed papers on separation and catalysis — and catalytic separation. He also authored almost 250 conference papers, 33 U.S. and Canadian patents and 6 book chapters. In fact, one of the discoveries that Chuang made at the University of Alberta involved a catalytic process that oxidizes volatile organic compounds (VOCs) in aqueous wastestreams into carbon dioxide and water. In doing so, Chuang addressed a problem that plagued conventional catalysts of the day, rendering them ineffective in aqueous streams because of their propensity to absorb water (*CE*, August 1992, p. 19).

While at the University of Alberta, Professor Chuang's separation apparatuses included a 1-ft dia. mass-transfer column that often separated methanol from isopropanol, and methanol from water. Using those apparatuses and others, the Alberta team of investigators demonstrated the impacts of surface tension and surface-tension gradient on distillation tray efficiencies. A 1993 tray-efficiency model showed that liquid-phase mass-transfer resistance is much greater than that predicted by other, older models. A 2004 paper described the results when six different systems were distilled using a 74-mm dia. Oldershaw column. The systems having positive surface-tension gradients exhibited froth stabilization and higher tray efficiencies.

Nobody spent more time studying the combined use of trays and packings in distillation columns than Professor Chuang and his Alberta team, says Resetarits. "They showed that the use of packing, on and between trays, can increase tray efficiencies. They also showed that trays can be used as redistributors in packed columns. And, in a 2007 paper, they described how jetting (as opposed to bubbling) affects tray efficiencies." Currently, Professor Rob Whiteley's team at Oklahoma State University is using the 2007 paper as the basis for a new valve-tray-efficiency model, Resetarits adds.

Chuang has received numerous awards from Canadian societies. His expertise has been passed down to his graduate students, and therefore continues to expand its reach. For example, Dr. G.X. Chen leads Praxair distillation research efforts; Dr. Z. P. Xu leads UOP's tray and packing research program; and Dr. D. Remesat designs columns for Koch-Glitsch in Western Canada.

Chuang loves to golf and spend time with his wife Ting. He is far from retirement, says Resetarits, consulting regularly for the Chinese Petroleum Corp. (Chia-Yi, Taiwan; www.cpc.com.tw).

A copy of Professor Chuang's impressive bibiliography can be obtained by contacting Mike Resetarits at resetarits@fri.org. ∎

Rebekkah Marshall
rmarshall@che.com

Letters

Discussions on storage tanks

January, Letters, p. 6: Mr. G. Moczulski comments on the November 2009 Facts at Your Fingertips "Aboveground and Underground Storage Tanks" makes the statement that storage tanks in vaults are regulated as aboveground storage tanks. The inference is that only regulations for aboveground storage tanks apply to such installations. This is true only for the tank itself.

For installations that store flammable or combustible liquids, the vault is governed by Chapter 25 of the 2008 edition of NFPA 30, Flammable and Combustible Liquids Code. (Chapters 21 and 22 of this code apply to the tank itself.)

Chapter 25 establishes construction requirements for the vault, including a requirement for anchoring the vault, so that it cannot "float" due to high groundwater levels. The chapter also includes requirements for the following: means to admit a fire suppressing agent; possible need for hazardous (classified) electrical utilization equipment and wiring; containment and drainage of spills; ventilation systems; vapor and liquid detection and alarm systems; and so on.

While NFPA 30 applies only to flammable and combustible liquids, some of the provisions of Chapter 25 would likely be considered appropriate for storage of liquids with other hazards. Of course, the designer must factor in the cost of all these features, as well as the cost of proper inspection and maintenance. NFPA 30 is adopted in the laws of more than 30 U.S. States.

Robert P. Benedetti, CSP, PE
National Fire Protection Assn., Quincy, Mass.

Postscripts, corrections

January, Updating The Rules for Pipe Sizing, pp. 48–50: Several values in Table 1 do not match exactly with the values published in the referenced article (*CE*, May 1999, pp. 153–156, Table 2): 1) The value of K for 1998 does not match as it should with the value of the original article issued in May 1999. Specifically, in Table 2 of the 1999 article, $K = 0.07$ for 1998 prices, while in Table 1 of the 2010 article K is equal to 0.04 for 1998 prices; 2) In the 1999 article (Table 2), the value of M is 0.575 for 1998 prices, while in Table 1 of the 2010 article, $M = 0.102$ for 1998 prices. In both cases, the older article is in error. Meanwhile, the author further notes that the value of K, energy cost (0.04), for 1998 year is correct in the 2010 article but has been rounded. The value of 0.0448 was used to obtain the corresponding value of M (0.102) for 1998. Also, the value of K for 2008 prices (0.07) was rounded. Considering more decimals (0.0716), the corresponding value of M was obtained (0.064) for 2008 prices.

April, Economic Indicators, p. 80: The 2nd and 1st Q 2009 Marshall & Swift Equipment Cost Indices are incorrect. Corrected values appear on p. 72 of this issue. Our thanks to Peter L. Hartwell, business manager at Covanta Energy, for bringing this to our attention.

April, Polysilicon Production, pp. 21–26: The majority owner of Hemlock Semiconductor Group is Dow Corning (www.dowcorning.com), not Dow Chemical Co. as reported. ∎
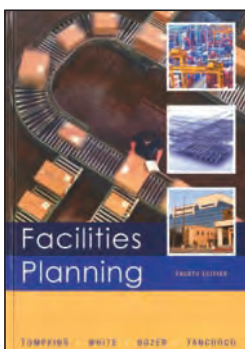
Facilities Planning, Fourth edition. By James A. Tompkins, John A. White, Yavuz A. Bozer and J.M. Tanchoco. John Wiley and Sons Inc., 111 River Street, Hoboken, NJ 07030. Web: www.wiley.com. 2010. 854 pages. $167.95.

Reviewed by Victor Edwards, Aker Solutions Americas Inc., Houston, Texas

Could facilities planning become a new paradigm in chemical engineering?

Engineering has long been enriched by applying science, mathematics and other fields to industrial pursuits. Chemical engineering began as an offshoot of industrial chemistry and mechanical engineering. Unit processes, unit operations, thermodynamics and chemical kinetics are among the paradigms that helped define the emerging discipline of chemical engineering in the first half of the 20th century. The history of chemical engineering is peppered with examples where advancing science was applied to industry and had profound impact.

Facilities planning — an integral part of commercial-scale chemical process operations — continues to evolve as a discipline, drawing on expertise and best practices from industrial engineering, manufacturing engineering, business management and operations research. Chemical engineers practice facilities planning in designing a process plant, but chemical engineering texts have not formally and comprehensively addressed the area. For example, one classic book on plant design devotes less than six pages to two major facilities planning issues — plant location and plant layout development. Similarly, useful AIChE guidelines on facility siting and layout cover process safety during siting, plant layout and equipment arrangement, but (appropriately for a process safety guidelines book), provides limited coverage of many other crucial aspects of facilities planning.

"Facilities Planning" (4th ed.) by Tompkins and others is a comprehensive text on industrial engineering, with numerous examples and references. The book discusses the full scope of strategic planning of the enterprise supply chain, from raw materials to customer products. It introduces several useful qualitative and quantitative tools, and would be a valuable reference for chemical engineers involved with enterprise planning, project planning and plant design.

The text begins by introducing the concept of strategic facilities planning as plant requirements are defined. The introductory section addresses facilities design, personnel requirements, as well as topics such as activity relationships and space requirements. The remainder of the book includes chapters on such topics as materials handling, layout planning models and quantitative facilties planning models. It concludes by discussing preparation, implementation and maintenance of facilities plans.

The book may help foster the formal incorporation of facilities planning principles into chemical engineering practice as a new paradigm in the field.

Bookshelf

Stoichiometry. Fifth edition. By Bharat I. Bhatt and Shuchen B. Thakore. Tata McGraw Hill Education PLC, 7 West Patel Nagar, New Delhi, India 110008. Web: www.tatamcgrawhill.com. 2010. 723 pages. $66.16
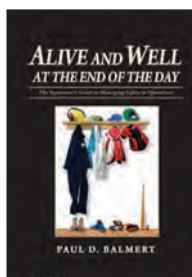
Core Engineering Concepts for Students and Professionals. By Michael R. Lindeburg. Professional Publications Inc., 1250 5th Ave., Belmont, CA 94002. Web: www.ppi2pass.com. 2010. 1,424 pages. $199.95

Alive and Well at the End of the Day: The Supervisor's Guide to Managing Safety in Operations. By Paul D. Balmert. John Wiley and Sons, 111 River Street, Hoboken, NJ 07030. Web: www.wiley.com. 2010. 274 pages. $69.95
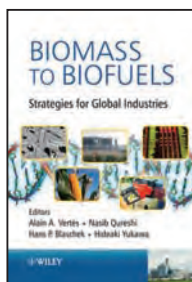
Biomass to Biofuels: Strategies for Global Industries. Edited by Alain Vertes, Nasib Qureshi, Hideaki Yukawa and Hans Blaschek. John Wiley and Sons, 111 River Street, Hoboken, NJ 07030. Web: www.wiley.com. 2010. 584 pages. $90.00
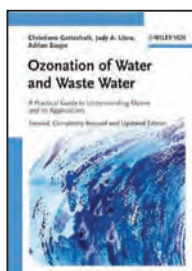
Ozonation of Water and Waste Water: A Practical Guide to Understanding Ozone and its Applications. By Christiane Gottschalk, Judy Ann Libra and Adrian Saupe. John Wiley and Sons, 111 River Street, Hoboken, NJ 07030. Web: www.wiley.com. 2010. 378 pages. $130.00
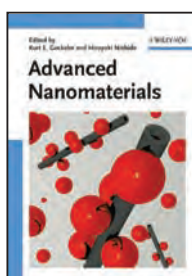
Omega Temperature Measurement Handbook, Seventh edition. By Omega Engineering. Omega Engineering Inc., One Omega Dr., Stamford, CT 06907. Web: www.omega.com. 2010. 2,000 pages. Free

Advanced Nanomaterials. Edited by Kurt E. Geckeler and Hiroyuki Nishide. John Wiley and Sons, 111 River Street, Hoboken, NJ 07030. Web: www.wiley.com. 2010. 954 pages. $460.00.
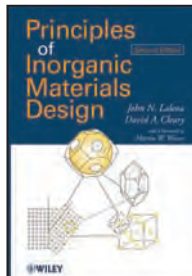
Principles of Inorganic Materials Design, Second edition. By John N. Lalena and David A. Cleary. John Wiley and Sons, 111 River Street, Hoboken, NJ 07030. Web: www.wiley.com. 2010. 585 pages. $145.00. ∎

Scott Jenkins

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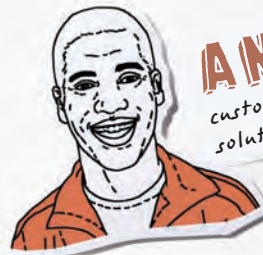
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CHEMENTATOR

This new process makes biogasoline from carbohydrates

In late March, the world's first demonstration plant for converting sugars directly into gasoline started up at the Madison, Wisc., facilities of Virent Energy Systems, Inc. (www.virent.com). The demonstration plant — part of a joint R&D collaboration of Virent and Shell (The Hague, the Netherlands; www.shell.com) — has the capacity to produce 10,000 gal/yr of biogasoline from beet sugar or other sucrose sources using Virent's patented BioForming platform technology.

The BioForming platform (flowsheet) combines Virent's core aqueous-phase reforming (APR) technology with conventional catalytic processing technologies, such as hydrotreating, condensation, dehydration and alkylation depending on the desired hydrocarbon product (gasoline, kerosene or diesel). The production of biogasoline in the demonstration plant includes feed preparation, hydrogenation, aqueous-phase reforming and acid condensation.

The APR step uses proprietary heterogeneous catalysts in series and parallel reactors operating at moderate temperatures (450–575K) and pressures (10–90 bar) to reduce the oxygen content of the carbohydrate feedstock. Reactions include reforming to make hydrogen, dehydrogenation of alcohols, hydrogenation of carbonyls, deoxy-

genation, hydrogenolysis and cyclization. *In situ* generation of hydrogen is one key aspect of the process, says Virent.
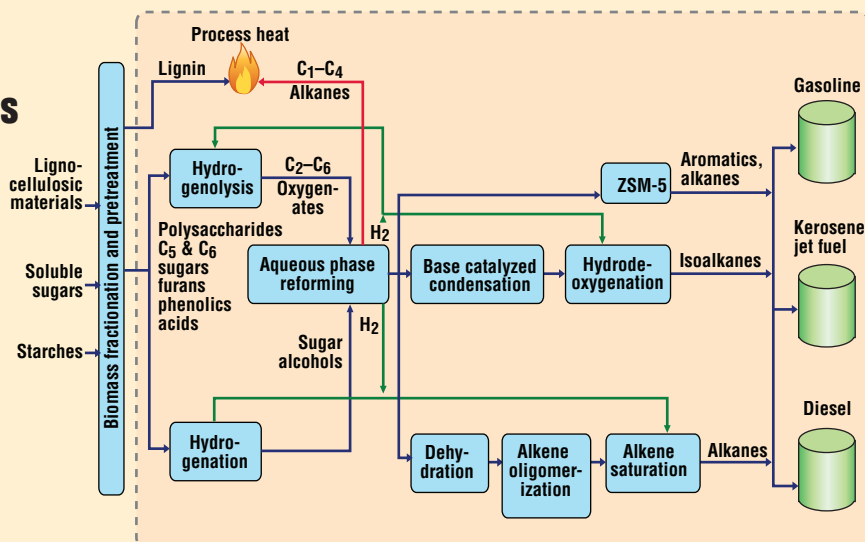
The process can utilize a broad range of carbohydrates, including those derived from non-food biomass. The technology offers an alternative to fermenting biomass-derived sugars into bioethanol, thereby eliminating the need for specialized infrastructure, engine modifications and blending equipment needed for gasoline using more than 10% ethanol, says the companies. (For more on bioethanol, see the news story on pp. 25–29).

Gasoline produced in the new plant will be used for engine and fleet testing.

A new Cl_2 process

Oxygen-depolarized cathodes (ODCs) will be used for the first time to produce chlorine on an industrial scale in a 20,000 metric ton per year (m.t./yr) electrolyzer at the Krefeld-Uerdingen chemical park in Germany. The plant will be constructed for Bayer MaterialScience AG (BMS; www.bayermaterial-sciences.com) by Uhde GmbH (Dortmund, both Germany; www.uhde.eu), and is slated for startup in the first half of 2011.

ODCs are O_2-consuming, gas-diffusion electrodes that

A process that makes 'green jet fuel' is slated for commercialization

Honeywell's UOP LLC (Des Plaines, Ill.; www.uop.com) has developed a process that makes a renewable, "drop-in" jet fuel from sustainable oils, including camelina, tallow, jatropha or algae. Similar to the the UOP/Eni Ecofining process for making Green Diesel fuel (*CE*, May 2007, p. 18), the Renewable Jet Process is a two-stage process. In the first step, the natural oils are first hydroprocessed to remove oxygen from the triglycerides to form straight-chained C_{16}–C_{18} paraffins, and propane as a byproduct. The wax-like paraffins are then isomerized into branched paraffins to improve cold-flow properties and reduce the cloud point. But unlike the Ecofining process for making diesel, this second step also

performs selective cracking to yield shorter-chained (C_{10}–C_{14}) synthetic paraffinic kerosene (SPK) needed for jet fuel, explains Graham Ellis, UOP's biorenewable energy business manager.

The SPK produced by the process meets all the necessary specifications (flash point, freeze point and stability) of petroleum-derived aviation fuel. However, it contains no aromatics, so to make a drop-in fuel, the SPK must be blended with conventional jet fuel (up to 50 vol.%), says Ellis. The fuel has been tested in a number of aircraft over the past two years — most recently by the U.S. Air Force last month — using a 50:50 blend of conventional JP-8 fuel with Green Jet produced by a 100-bbl/d

toll manufacturing facility in Texas.

Ellis says the technology is now ready for commercialization, and UOP is already performing engineering for AltAir Fuels (Seattle, Wash.) for a 100-million gal/yr production facility to be located at the Tesoro oil refinery in Anacortes, Wash. Scheduled for startup in 2012, the plant will produce renewable fuel from camelina oil sourced from Sustainable Oils (Bozeman, Mont.), which has the largest camelina research program in North America. Last December AltAir Fuels signed a memorandum of understanding with 14 major airlines from the U.S., Mexico, Canada and Germany for the sale of up to 750 million gallons of renewable jet fuel.

Bioethanol as a feedstock for 'green' polymers

Efforts to make a completely sustainable route to polymers based on vinyl acetate monomer (VAM) are progressing at Wacker Chemie AG (Munich, Germany; www.wacker.com). VAM — a precursor for polyvinyl acetate and ethylene-vinyl-acetate copolymers used for making dispersible polymer powders — is normally made by the reaction of acetic acid and steam-cracker-derived ethylene. Wacker is developing alternative routes to both acetic acid and ethylene starting with ethanol, the idea being that bioethanol derived from cellulose will soon become economically viable as a renewable feedstock.

Furthest along is Wacker's ACEO process (flowsheet), in which acetic acid is made by the direct oxidation of ethanol. The reaction takes place in a fixed-bed reactor at a temperature of over 200°C over a proprietary oxidation catalyst that the company developed in house. Heat from the exothermic reaction is recovered to make high-pressure steam, which is both exported and used for purifying the acetic acid by distillation. The process has been demonstrated in a 500 m.t./yr pilot plant, which has operated for over six months at Wacker's Burghausen, Germany, site. Acetic acid yields of over 90%, with 96 mol.% selectivity, have been achieved, says Fridolin Stary, senior vice president, corporate R&D.

Whereas conventional oxidation processes produce formic acid as a byproduct, thus requiring "exotic" materials to protect against corrosion, the high selectivity of the ACEO process enables the use of stainless-steel construction, says Stary. The ACEO process is ready for commercialization, and is expected to be competitive when the price of bioethanol drops to about $330/m.t., he says.

Wacker is open to licensing the technology, and anticipates a market potential in regions with large bioethanol capacity, such as the U.S. and Brazil.

Wacker is now building a pilot plant for developing an improved process to make bioethylene. The process is based on the dehydration of ethanol at temperatures of 300–400°C. Stary points out that today, only very few bioethylene pilot plants are operating in the world, such as that of The Dow Chemical Co. and Braskem S.A. in Brazil.
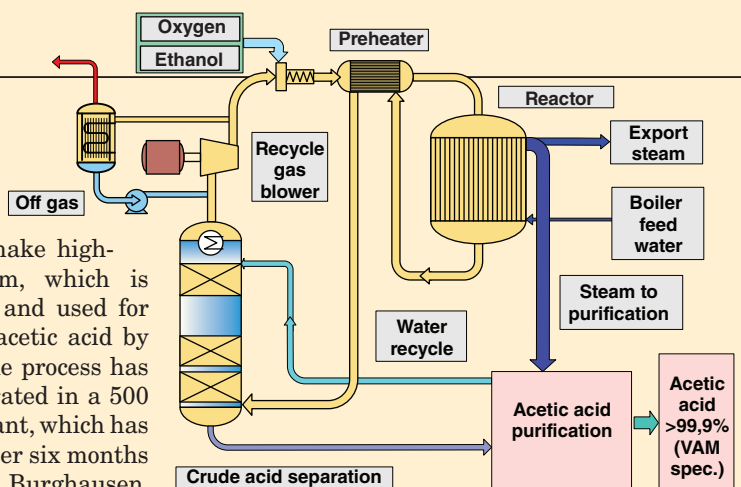
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Revamped hydrotreater co-processes light gas oil and tall oil derivative to produce ULSD

Co-processing of biomass-derived feed with petroleum feed for the production of diesel fuel is a tricky business, given that the former (unlike petroleum) contains oxygen. The oxygenates can be removed by hydrotreating, which converts the biofeed to normal paraffins, but this consumes large amounts of H_2 and the exothermic reactions can cause excessive temperatures. Also, biomass contains acids that can cause corrosion in the hydrotreater and other equipment.

A process that is said to overcome these problems has been developed by Haldor Topsøe A/S (Lyngby, Denmark; www.topsoe.com) and is being commercialized in a revamped hydrotreater that will be started up shortly by Preem AB (Gothenburg, Sweden). The plant will produce 10,000 bbl/d of ultra-low-sulfur diesel fuel (ULSD) from a mixture of light gas oil (LGO) and up to 30% raw tall diesel (RTD). RTD is produced by transesterification of tall oil,

a byproduct of kraft pulping. This converts most of the oil's free fatty acids to fatty acid methyl esters (FAMEs), but resin acids are unconverted and can cause corrosion, says Rasmus Egeberg, Topsøe's project manager for distillate hydrotreating.

In Topsøe's process, part of the RTD is mixed with the LGO just prior to entering the hydrotreater, thus avoiding corrosion in the upstream fired heater, heat exchanger and pipes. The remaining RTD is injected between the first two of the reactor's four beds, serving both as a liquid quench to control the reaction temperature and as a way to minimize corrosion by reducing the concentration of acidic components in the top of the reactor. The process uses a proprietary hydrodeoxygenation catalyst and a high-activity nickel-molybdenum catalyst for hydrodesulfurization.
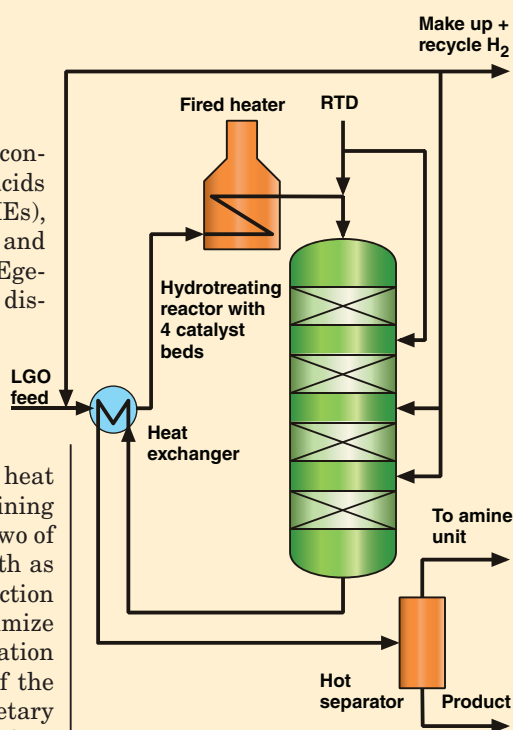
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Destroy HFCs and recover CaF$_2$ with this process

A process that destroys hydrofluorocarbons (HFCs) and recovers high-purity calcium fluoride has been developed by chemical-engineering professor Hideki Yamamoto at Kansai University (Suita City, Osaka; www.cheng.kansai-u.ac.jp/Process) in cooperation with Shiraishi Kogyo Kaisha Ltd. (Amagasaki City, Osaka; both Japan; www.shiraishi.co.jp/kogyo).

The technology is based on calcium hydroxide, a byproduct from the process used to purify natural calcium carbonate. A mixture of Ca(OH)$_2$ and HFCs is first decomposed at 500–550°C into CaF$_2$, carbon-based residues, water and CO$_2$ along with unreacted materials, such as CaO and CaCO$_3$. The products are then heated to 700°C, which burns away the carbons, then dissolved in a mixture of HCl and HF acids. The HCl reacts with CaO and CaCO$_3$ to form CaCl$_2$, which then reacts with HF to form CaF$_2$ — a sparingly soluble salt that precipitates. Yamamoto has recovered CaF$_2$ with 95–98% purity using the method.

A patent for the technology has been applied for, and the researchers are planning to demonstrate the process in compact reactors suitable for companies that manufacture HFCs as alternatives for chlorofluorocarbons (CFCs), as well as for treating CFCs.

HYDROTREATER (*Continued from p. 14*)

Egeberg says the reactor operates at essentially the same conditions of temperature and pressure as a standard diesel fuel hydrotreater. Hydrogen consumption is "significantly higher," due to the hydrodeoxygenation reactions, but heater duty and fuel consumption are lower. Overall, the process economics are "very favorable," he says, and the revamp will be paid back "in a short time." Egeberg says the design allows for processing other triglyceride feeds, including animal fat, oil from algae and used oils.

separate caustic from the O$_2$ side. The O$_2$ diffuses into the porous electrode structure to catalyst centers and reacts with cathodic water to produce hydroxide ions (*CE*, May 2007, pp. 50–55). Because the ODC allows the electrolyzer to operate at lower voltages, energy requirements for producing Cl$_2$ are reduced by up to 30%, says BMS. The commercial unit will use ODCs in NaCl-based electrolyzer cells developed by by Uhde and UhdeNora S.p.A. (Milan, Italy; www.uhdenora.com). BMS has also used its ODC technology based on hydrochloric-acid electrolysis at the Bayer Integrated Site Shanghai in China, and in Brunsbüttel, Germany.

Biomass to SNG

Haldor Topsøe S/A (Lyngby, Denmark; www.topsoe.com) will participate in the design of what is said to be the world's first plant for producing sub-

Distillation-tray downcomer design improves mass transfer efficiency

Liquid flow direction

A new approach to the design of the downcomer portion of distillation column trays — presented at the recent American Institute of Chemical Engineers (AIChE) Spring 2010 meeting (San Antonio, Tex.; March 21–25) — promotes a uniform fluid flow pattern, which improves mass transfer efficiency.

The Downcomer Distributor was developed through a joint research program between AMT International Inc. (Plano, Tex.; www.amtintl.com) and Petronas (Kuala Lumpur, Malaysia; www.petronas.com.my) with an objective to eliminate deviations from an ideal fluid-flow pattern that occur on typical distillation trays, which result from recycling of fluid on the tray and by the existence of stagnant regions of liquid.

The Downcomer Distributor technology results in *directional* flow and *distribution within* the downcomer itself and as the liquid exits the downcomer.
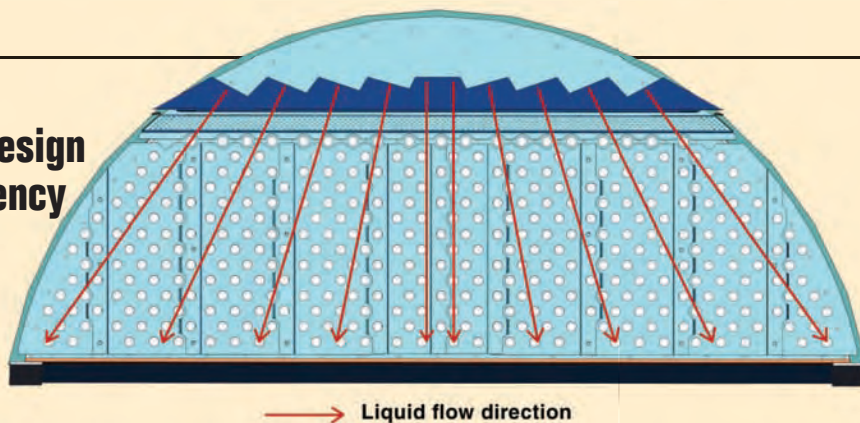
Inside the AMT Downcomer Distributor (diagram), liquid is distributed according to pre-determined proportions by "uniquely arranged, slanted and triangle-shaped discharge ports" that initiate and maintain a uniform plug-flow pattern.

In testing, the Downcomer Distributor consistently resulted in approximately 5–10% greater tray efficiency compared to existing downcomer configurations under normal tray operating conditions and with the same active valve tray. AMT says that combining the Downcomer Distributor technology with its high-performance Advanced Dispersion Valve (ADV) Trays has demonstrated efficiency increases of 24% and 29%, respectively, for liquefied petroleum gas (LPG) and depropanizer columns of a large-scale commercial gas plant.

In addition to increasing mass-transfer efficiency, the elimination of stagnant zones of liquid on the trays extends the column runtime, since stagnant zones tend to foul in dirty service, says the manufacturer.

The Downcomer Distributor technology has been applied at several commercial distillation columns, starting in 2008, including at several Petronas plants.

Surface-structured RO membrane couples fouling resistance with flux

Engineers at the University of California–Los Angeles (UCLA; www.ucla.edu) have developed a new class of highly permeable reverse-osmosis (RO) membranes for water desalination that incorporates a "brush layer" of hydrophilic polymer chains anchored to the membrane surface. Brownian motion of the surface-anchored polymer chains blocks foulants, such as bacteria, mineral crystals and proteins, from adhering to the membrane. The membrane also resists mineral scaling by preventing scalant materials from nucleating on the surface.

Membrane assembly depends on a surface-modification method in which a jet of ambient-pressure plasma is directed over the surface of the polyamide thin-film composite membrane to create functionalized sites for polymer chain attachment. The plasma surface treatment does not require vacuum conditions, making the approach amenable to commercial scale-up, says UCLA professor Yoram Cohen, the project's leader.

Depending on the application, the engineers can vary the separation between polymer chains from about 10 to 50 nm, as well as the length of the chains, from a few monomers to about 1,000 monomers.

The UCLA engineers have developed considerable expertise in the surface modification technique, Cohen explains, learning in the process how to construct membranes that, when surface-modified, would possess the desired flux and fouling-resistance properties. The group has begun a field demonstration of the membrane's ability to resist fouling, and hopes to demonstrate a continuous process to synthesize the membranes in a year. The goal for a commercially viable product is two years.

Improving enzyme performance for making chemicals

By genetically modifying *E coli* — introducing four enzymatic genes from bacteria of the *Clostridium* family — Mitsui Chemicals Corp. (Mitsui, Tokyo, www.mitsuichem.com) has increased the selectivity for fermenting glucose into isopropyl alcohol (IPA) from 40% to up to 70%. The company has also developed biocatalysts for producing glucose from molasses and from wood-based biomass.

The results are part of an ongoing project in which Mitsui plans to develop enzymatic processes for making four products: IPA for producing propylene; hydroquinone as a precursor for producing phenolic and polycarbonate resins; and D- and L-lactic acid for polylactic acid production. The company is now conducting studies needed for scale up in three, 300-L fermenters, and plans to have sample products based on the enzymatic routes available within 1–2 years.

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www.berndorf-usa.com

These microfluidic sensors can be made with a sewing machine

A low-cost method for fabricating microfluidic diagnostics devices using cotton, paper, or other multifilament threads has been developed by a team from Monash University (Melbourne, Australia; www.eng.monash.edu.au). The devices can be used to provide qualitative and, at least, semi-quantitative analyses of fluids, such as blood and urine for medical diagnostic purposes. They can also be used to detect pollutants in water and food products.

Several concepts have been developed for low-cost, portable, and field-based diagnostics devices, due to their potential to provide affordable healthcare and environmental monitoring to remote and developing regions. The idea of using electronic threads for human health monitoring has been reported in many studies, but the threads have usually been metal-based, or made of carbon nanotubes coated with polyelectrolytes. The Monash team has used cotton thread because the gaps between fibers provide capillary channels for liquids to wick along the threads; there is no need for an external pump. "To the best of our knowledge, there has been no work reported using cotton thread or other multifilament threads for fabricating simple and low-cost microfluidic analytical devices," says team leader Wei Shen, a professor in the dept. of chemical engineering.

The researchers make 3D structures by sewing the cotton thread onto other materials such as polymer film. High-density-thread microfluidic channels can be fabricated to enable the transportation of several liquids through the structure without mixing. Thread- and thread-paper-based sensors have been made that incorporate colorimetric indicators for nitrite ion and uric acid. In general, the patent-pending devices can be used for colorimetric, electrochemical, chemiluminescent, electrochemiluminescent assays and electrophoresis, achieving measurements with 3% error or better (5% error is considered semi-quantitative), says Shen. ∎

(Continued from p. 16)

stitute natural gas (SNG) from biomass. The project, owned by the Gothenburg Biomass Gasification (GoBiGas) consortium, with main owner Göteborg Energi AB (Sweden, www.goteborgenergi.se), aims to produce 20 MW of Bio-SNG to be fed into the existing gas grid. Approximately 300 ton/d of wet forest residues will be gasified. The plant, located next to the Rya District Heating Plant in Gothenburg, Sweden, is scheduled to start up in 2012.

The complete process for making SNG includes biomass gasification, tar scrubbing, gas conditioning and methanation. Topsøe will supply gas conditioning and its TREMP methanation technology, which was also selected for making SNG from coal in China (*CE*, December 2009, p. 12). The gasifier will be supplied by Metso Power (Helsinki, Finland; www.metso.com) and Repotec GmbH (Vienna, Austria; www.repotec.at), using Repotec's indirect gasification technology. ❏

A 'PERFECT STORM' FOR U.S. PETROLEUM REFINING INDUSTRY?

Refiners are anxious about excess capacity, lower sales, and the prospect of greenhouse gas regulations

FIGURE 1. The U.S. demand for diesel fuel is expected to increase in the future, while the consumption of gasoline from petroleum will decline

L ess than two years ago, U.S. petroleum refiners were in the middle of an expansion and modernization program that was designed to add more than 1-million bbl/d to meet the growing demand for fuels, especially diesel fuel. Much of the investment was for cokers, in anticipation of increasing imports of heavy oil from Mexico, Venezuela and Canada.

As it turned out, the demand for petroleum fuels has dropped because of the economic recession, and the industry has 1–2-million bbl/d of excess capacity, said William Klesse, chairman of the National Petrochemical and Refiners Assn. (NPRA, Washington D.C.; www.npra.org). Klesse, who is CEO of Valero Energy Corp. (San Antonio, Tex.; www.valero.com), spoke at the NPRA's recent national meeting in Phoenix, Ariz. He added that Valero had shut down its Delaware City Refinery "because we were losing so much money."

About 1.25-million bbl/d of U.S. capacity needs to be "rationalized" because it is uneconomical, says Stephen Jones, vice president, market services with Purvin & Gertz Inc. (Houston; www.purvingertz.com). Which units are actually shut down depends on the economic state of each refinery, he says, and includes such factors as the refinery's configuration, market competitiveness, how well it is meeting new fuels requirements, an appropri-

ate crude supply, capacity for upgrading heavy feeds, and the ownership structure (for example, whether the refinery is independent or part of a large company).

Meanwhile, imports of heavy oil from Mexico and Venezuela have dropped, particularly from Mexico, where production has declined. Partly because of this and partly because of industry expansion, U.S. coker utilization dropped below 70% last year, says Jones.

For the future, although the market for diesel fuel is predicted to grow, the demand for petroleum-derived gasoline is expected to decline about 20% by 2022 (Figure 1). The reasons for the dropoff are government-mandated tighter fuel-efficiency requirements for new vehicles and the increasing use of ethanol (see story on p. 25). On top of all this, refiners are uneasy about pending federal rules for greenhouse gas (GHG) regulation (basically carbon dioxide), which they feel would impose an unfair burden on their business.

The combination of these multiple legislative and market-driven changes signals the coming of "a perfect storm," according to Jon Moretta,

director of Jacobs Consultancy's Petroleum, Chemicals and Energy Practice (Chicago, Ill.; www.jacobs.com), who spoke at the NPRA meeting. Charles Drevna, president of NPRA said: "We are facing proposals [on GHGs] from both the Administration and Congress that threaten the future of the domestic refining and petrochemical industry" (see box on p. 23).

Oil upgrading

The high price of oil has brought a new lease of life to some old oil-upgrading processes that until recently were considered uneconomical. One is the Veba Combi Cracker (VCC) hydrocracking process for residual oil. Invented by Germany's Veba Oel in 1913, it was used to produce oil from coal in a dozen plants, and for resid upgrading in the 1950s. Now, the process is being offered for upgrading resid, heavy oil and coal by KBR (Houston; www.kbr.com) under a collaboration agreement with BP (London; www.bp.com), which acquired Veba in 2001 and has further refined the technology.

VCC is a two-step process that converts 95% of resid (including 90% of the

asphaltenes) to about 50% diesel fuel, 15% naphtha and 30% vacuum gas-oil. In the first stage, feed is slurried with a proprietary nonmetallic additive in an ebullated bed at 180–200 bar and more than 400°C. The second stage employs a standard nickel-molybdenum hydrotreating catalyst in a fixed bed.

In contrast, conventional ebullated-bed hydrocrackers achieve less than 80% conversion, and most fixed-bed resid hydrocrackers obtain only about 20% conversion, says Anand Subramanian, KBR's vice president of refining. He adds that another advantage of the VCC slurry-phase method is that it avoids the fouling problem seen in conventional ebullated-bed and fixed-bed hydrocrackers.

The economic threshold for VCC is a crude price of $60/bbl, says Subramanian, "and we believe the pressure on crude prices will be only higher in the future because of [tighter] supply and demand. The technology was probably invented way before its time, but now its time has come."

New process improvements

Despite the turndown and the decline in the supply of heavy crude oil, the demand for hydrogen has continued to be robust, says David Burns, director of global business development for hydrogen with Praxair Inc. (Danbury, Conn.; www.praxair.com). "The market for hydrotreating has continued to increase and we anticipate good future growth for that market," says Burns, who is located in Houston. (For more on hydrogen, see cover story, pp. 34–38.)

A relatively simple modification that allows a refiner to increase H_2 production from an existing steam methane reformer (SMR) without adding capacity is available from Praxair. Praxair's solution, called oxygen enhanced reforming (OER), involves the injection of oxygen into the SMR furnace to increase the O_2 concentration in the combustion air to 22–23%. This boosts the furnace firing rate without exceeding process limits and increases H_2 production by 10–15%, says Gregory Panuccio, a development associate with Praxair.

The additional O_2 may be premixed with the combustion air by a sparger or injected into the furnace's combustion zone by lances (usually one lance per burner — see Figure 2). A sparger requires a single penetration into the air ductwork, whereas lances require multiple penetrations into the furnace, says Panuccio. However, a sparger "slightly increases" the production of thermal NOx (oxides of nitrogen), while a lance installation will not.

Either system can be installed with a one-day plant outage at a cost of $500,000–$1.5 million, depending on the configuration of the SMR. This compares with $7–10 million for a pre-reformer retrofit for a 100-million-scf/d SMR, says Panuccio. The cost of incremental H_2 is similar to the baseload H_2 cost. Praxair has field-tested the process on a 5-million-scf/d SMR and plans to start up the first commercial system, of similar size, next year.

In a related development, Praxair is ready to commercialize a refinery gas processor (RGP) that conditions refinery fuel streams for the production of H_2 from an SMR. Panuccio notes that refinery gases are often not suitable for SMR feed without further processing because their olefin content causes coking of the SMR catalyst. The olefins may be hydrogenated to paraffins before going to the SMR, he says, "but if the olefin content is 6% or more you can't use traditional hydrotreating because of the exotherm."

Praxair's RGP solves this problem by using a noble metal-based catalyst to hydrogenate the olefins. The catalyst can tolerate temperatures of more than 1,000°F, versus 700–800°F for a conventional hydrogenation catalyst, says Panuccio. The process has been tested in a refinery at a scale of 5,000 scf/h, he says, and the company is negotiating with several potential customers.

Meanwhile, Air Liquide and its Lurgi subsidiary are offering a new generation of steam methane reformers, designed to capture more CO_2 from the offgas. The new SMRs will

capture 63–92% of the CO_2, versus 59% for current units, says Dennis Vauk, senior international energy expert for the Energy Market Group of Air Liquide Large Industries U.S. LP (Houston; www.airliquide.com).

Two options for capture technology are offered: amine contacting and cryogenic purification. Also, the pre-reformer, reformer furnace and shift section are optimized to reduce CO_2 production. Vauk notes that amine contacting is done upstream of the SMR pressure swing adsorption (PSA) unit, while the cryogenic system captures CO_2 from the PSA tail gas, where the CO_2 is more concentrated. The cryogenic method, which is less expensive, will capture 63–73% of the gas at a cost of \$30–40/(short) ton for a large SMR, says Vauk. An amine may be used for higher removal rates.

An ultrasound-assisted oxidative desulfurization process that removes sulfur from gasoline and diesel fuels without the use of H_2 has been developed by SulphCo (Houston; www.sulphco.com). Fuel is mixed with hydrogen peroxide and a proprietary oxygen-transfer catalyst in a static mixer, then passes through an ultrasonic chamber, where 18-kHz ultrasonic waves cause cavitation to promote oxidation.

SulphCo has tested several diesel and gasoline feeds and has consistently reduced the sulfur content to below 10%, says Florian Schattenmann, vice president and chief technology officer. "For example, we have oxidized all the sulfur compounds in a diesel fuel from 500 ppm to 5 ppm in a single pass." The residence time is less than 500 ms, at ambient temperature and pressure, he says, and the oxidative reaction is so fast "a reactor the size of a soft-drink can could process 4,000 bbl/d of fuel." In contrast, he notes, hydrodesulfurization requires high heat and pressure, and removal of the final 1% of sulfur consumes 40% of the total H_2 used.

The economic benefit of the oxidative system depends on the availability of H_2 at a refinery and on the amount of refractory compounds in the feed. Schattenmann says the most economical use of the system is to treat refractories after the "easy" sulfur compounds have been removed by hydrotreating. In these cases, the estimated net benefit is \$0.70–1.00/bbl. SulphCo is testing product streams for several potential customers.

Catalysts

Several new catalysts that are designed to improve the efficiency of fluid catalytic crackers (FCCs) are on the market. BASF Catalysts (Iselin, N.J.; www.catalysts.basf.com) offers two such catalysts: Stamina, designed to maximize diesel output with high bottoms conversion from contaminated resid feeds; and NaphthaMax III, which is said to provide increased zeolite stability and coke selectivity, with higher gasoline yields than earlier NaphthaMax catalysts. NaphthaMax uses BASF's Distributed Matrix Structure (DMS), while Stamina is based on the company's Proximal Stable Matrix and Zeolite (Prox-SMZ) technology.

In both cases the zeolite and active matrix of the catalyst are created simultaneously in a single step, rather than being synthesized separately and physically combined into particles, says Fabian Florez, global marketing manager for refining catalysts. This allows intimate contact between the matrix and the zeolite, with an ultra-low sodium content, he says.

Stamina has larger than normal pores that help process heavy feeds. In a commercial refinery trial, the catalyst improved bottoms upgrading by 45% and reduced delta coke by 25%. NaphthaMax III has also been tested in a refinery and achieved an 0.8% improvement in gasoline yield at a constant coke level, says Florez.

BASF also has a new FCC catalyst system that allows refiners to switch more rapidly between the production of gasoline and diesel fuel in response to market demand and prices. The co-catalyst system consists of three components: a Prox-SMZ catalyst (HDUltra) that maximizes the production of light cycle oil (LCO); a DMS catalyst, called Converter, for gasoline production; and a base FCC catalyst that es-
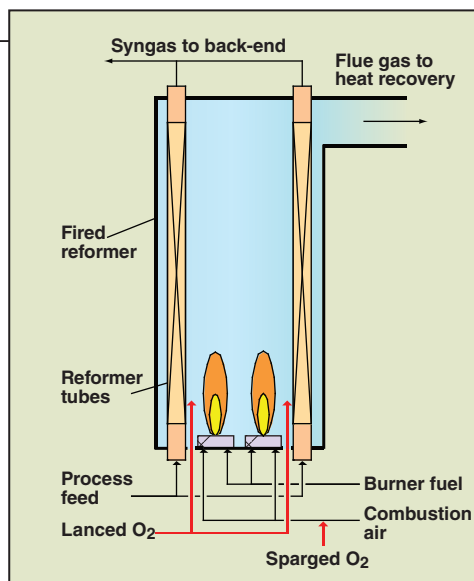
FIGURE 2. Praxair's oxygen-enhanced reforming technology increases hydrogen production from a steam methane reformer by injecting oxygen into the SMR furnace

tablishes the core performance of the FCC (that is, it is not optimized for either gasoline or LCO).

When more distillate is required, 30% of the base catalyst is replaced by HDUltra, says Tim McGuirk, marketing manager for FCC additives, who is located in Houston. For increased gasoline production, 30% is replaced by Converter. The switch from one product to another takes only about one-third of the time required for catalyst reformulation and the yield is essentially the same. In a 200-day refinery test, he says, the co-catalyst system increased profit by $2.5 million, or an average of $0.23/bbl of fresh feed.

A new fluid catalytic cracking (FCC) catalyst for gasoline production called Alcyon has been introduced by Grace Davison (Columbia, Md.; www.grace.com). The catalyst has the highest activity for a given surface area of any FCC catalyst technology, demonstrating 20% higher activity than competitive offerings, asserts Rosann Schiller, product manager.

Alcyon is a zeolite catalyst with an alumina binder. In tests in a commercial refinery, Alcyon has increased unit conversion (gasoline and lighter) by 2 vol.% which is significant, says Schiller. She adds that because of its high activity, the catalyst has a 20% lower replacement rate than conventional cracking catalysts, thereby maximizing profitability and reducing operating costs. ■

Gerald Parkinson

BIOALCOHOLIC FUELS

The U.S. is turning to bioethanol as one of its saviors from foreign oil; but another alcohol is emerging that promises to be a better renewable fuel supplement

Last year (2009) was a record year for U.S. ethanol production, with 200 biorefineries producing an estimated 10.6-billion gallons, according to the Renewable Fuels Assoc. (RFA; Washington, D.C.; www.ethanol-rfa.org) in its recently published report, "The 2010 Ethanol Industry Outlook." An additional 20-billion gallons of ethanol were produced elsewhere around the globe in 2009 — a 400% increase over production in 2000, says RFA. Driving the boom are a combination of national incentives and programs aimed at replacing the dwindling and increasingly expensive petroleum-based fuels with so-called renewable fuels. (For more on petroleum refining, see the story on p. 21.)

In the U.S., the growth of ethanol production has been sparked by the the U.S. Environmental Protection Agency's (EPA; Washington, D.C.) National Renewable Fuels Standard (RFS) program, which requires — by law [the Energy Independence and Security Act (EISA) of December, 2007] — the use of 36-billion gallons of renewable fuels by 2022, of which 16-billion gallons must come from cellulosic sources. In February, the EPA released its final rule for the expanded standard (RFS2), which defines renewables and how they are to be phased in (Table 1). To meet the demand of the RFS, an additional 16 plants are being built or expanded that will add an additional 1.4-billion gallons of new capacity, says RFA.

Ethanol as fuel

Pointing to Brazil's successful 30-year-old ethanol-fuel program, the U.S. ethanol industry believes it can meet the needs of RFS2 while touting the green benefits of ethanol as a fuel. The fact is, however, most cars in the U.S. can only handle gasoline with 10 vol.% (E10 fuel). Although engines can be designed to handle E85 offered in some states, other problems associated with ethanol — such as its lower energy content (fewer mi/gal compared to gasoline) and distribution problems (it can't be pipelined due to contamination) — means that ethanol will probably not be the panacea to end U.S. dependency on foreign oil. That's why a considerable push for alternative renewable fuels is underway, such as thermochemical methods for converting biomass into liquid fuels (see, for example, the Chementator on p. 11).

Another perceived problem with ethanol is the fact that most is made from grains (mainly corn in the U.S.) or sugar — both foods. This so-called first-generation bioethanol now has a negative public relations image to combat, namely, that using ethanol as fuel has driven up food costs, reduced food supplies and has taken over farmland that could be used for growing food crops. RFA claims this is a myth, and is actively campaigning to dispel it.

Myth or not, there is a tremendous R&D push for developing process technology to utilize the sugars bound up in cellulose — the most abundant renewable feedstock in the world — and lignocellulose to make second-generation bioethanol. At least 28 advanced biofuel companies have started, or are planning cellulosic and other biomass-based ethanol plants that will bring an additional 170 million gallons of production, with massive expansion following commercialization, says RFA (Table 2).

Ethanol from cellulose

Cellulose is a polymer of glucose (polysaccharide), which can be broken down into fermentable sugars by acid hydrolysis, in which a strong acid is used at high temperature.

The first cellulosic-ethanol demonstration plants to come on stream have been based on acid hydrolysis. For example, Verenium Corp. (Cambridge, Mass.; www.verenium.com) started up a 1.4-million gal/yr demonstration-scale facility at Jennings, La., which produces ethanol from regional feedstocks (including sugarcane bagasse and specially bred "energy cane") via proprietary cellulosic-ethanol technology.

In Verenium's process, biomass is first hydrolyzed by acid into a hemicellulose syrup (xylose and other C_5 sugars) and fiber residue (cellulose and lignin). The two streams are separated and individually fermented into dilute ethanol (beer) using proprietary bacteria. The cellulose fermentation uses commercial enzymes that are produced onsite by a fungus that can be "trained" to handle a given biomass.

TABLE 1. EISA RENEWABLE FUEL VOLUME REQUIREMENTS (billion gallons)				
Year	Cellulosic biofuel requirement	Biomass-based diesel requirement	Advanced biofuel requirement	Total renewable fuel requirement
2008	n/a	n/a	n/a	9.0
2009	n/a	0.5	0.6	11.1
2010	0.1	0.65	0.95	12.95
2011	0.25	0.80	1.35	13.95
2012	0.5	1.0	2.0	15.2
2013	1.0	a	2.75	16.55
2014	1.75	a	3.75	18.15
2015	3.0	a	5.5	20.5
2016	4.25	a	7.25	22.25
2017	5.5	a	9.0	24.0
2018	7.0	a	11.0	26.0
2019	8.5	a	13.0	28.0
2020	10.5	a	15.0	30.0
2021	13.5	a	18.0	33.0
2022	16.0	a	21.0	36.0
2023+	b	b	b	b

Notes:
a. To be determined by EPA through a future rulemaking, but no less than 1.0 billion gallons.
b. To be determined by EPA through a future rulemaking.
n/a = not applicable
EISA = Energy Independence and Security Act
Source: U.S. EPA, www.epa.gov

The beer from both fermentation streams is subsequently concentrated into fuel-grade ethanol by distillation. Biomass residue is burned to make steam for the process.

In February 2009, Verenium signed a second phase of partnership with BP (London; www.bp.com) to form a 50:50 joint venture company, Ver-cipia Biofuels, to develop a commercial cellulosic ethanol from non-food feedstocks. The joint venture (JV) is focussing on developing two projects in the Gulf Coast Region, the first in Highlands County, Fla., which is slated for startup in 2012.

More recently, enzymatic methods have been developed as an alternative to acid hydrolysis for breaking down cellulose. Enzymes have the advantage of operating at milder conditions, which reduces the degradation of sugars and thus boosts ethanol yields. For example, in January, DuPont Danisco Cellulosic Ethanol LLC (www.ddce.com) — a JV of DuPont (Wilmington, Del.; www.dupont.com), and Danisco A/S (Copenhagen, Denmark) — started up its first demonstration facility at Vonore, Tenn., which produces ethanol from non-food feedstocks, such as corn stover, cobs and fiber and switchgrass. The $50-million investment has the capacity to produce 250,000 gal/yr of ethanol. The fermentation is performed by genetically engineered *Z. mobilis* bacteria, which can metabolize both glucose and xylose.

To make production costs for such enzyme-based cellulosic facilities competitive with grain and sugar-based ethanol, enzyme producers have been working on ways to reduce costs. At RFA's Annual National Ethanol Conference last February, two such breakthroughs were announced, with Cellic CTec2 launched by Novozymes A/S (Bagsvaerd, Denmark; www.novozymes.com), and Accellerase DUET introduced by Genencore (Palo Alto, Calif.; www.genencor.com), a Div. of Danisco. Both enzyme products are said to be significantly more potent at breaking down biomass into fermentable sugars than existing technology (*CE*, March, p. 14 and 16). As a result, less enzyme is needed per gallon of ethanol.

Novel enzymes aside, new pretreatment steps are being developed that can further reduce production costs of cellulosic ethanol. At the ARS National Center for Agricultural Utilization Research (Peoria, Ill.; www.ars.usda.gov), ARS chemist Badal Saha conducted a five-year study that examined whether wheat straw could have commercial potential for cellulosic ethanol production. He found that he could access and ferment almost all the plant sugars in the biofeedstock when it was pretreated with alkaline peroxide and then broken down by enzymes. This process released even hard-to-reach sugars in the plant walls, which significantly boosted the overall ethanol output to around 93 gal/ton of wheat straw.

In a related development, Rajai

TABLE 2. PLANNED AND EXISTING CELLULOSIC ETHANOL PLANTS IN NORTH AMERICA							
Name	Location	Capacity (million gal/yr)	Start-up	Name	Location	Capacity (million gal/yr)	Start-up
AE Biofuels	Butte, Mont.	0.15	2008	Enerkem	Westbury, QC	1.3	2009
Coskata	Madison, Pa.	0.04	2009	Fiberight	Blairstown, Iowa	5.6	2010
Gulf Coast Energy	Livingston, Ala.	0.4	2009	Flambeau River Biofuels	Park Falls, Wisc.	6	2010
Iogen	Ottawa, Ont.	0.2	2004	Range Fuels	Soperton, Ga.	10	2010
KL Energy	Upton, Wyo.	1.5	2008	ZeaChem	Boardman, Ore.	1.5	2010
Mascoma	Rome, N.Y.	0.2	2009	Abengoa Bioenergy	Hugoton, Kan.	11.4	2011
POET	Scotland, S.D.	0.02	2009	Alltech Ecofin	Washington Co., Ky.	1	2011
Verenium	Jennings, La.	1.4	2009	ClearFuels Technology	Commerce City, Colo.	1.5	2011
BlueFire Ethanol	Lancaster, Calif.	3.7	2010	Fulcrum BioEnergy/Sierra Biofuels	Reno, Nev.	10.5	2011
DuPont Danisco Cellulosic Ethanol	Vonore, Tenn.	0.25	2010	Gulf Coast Energy	Mossy Head, Fla.	25	2011

Source: Biotechnology Industry Organization

Atalla, chief scientific officer of Cellulose Sciences International, Inc. (Madison, Wisc.; www.celscint.com), explained to delegates at the Spring meeting of the American Chemical Soc. (San Francisco, Calif.; March 21–25) about a discovery he made in the 1970s that has the potential to decrease enzyme costs by a factor of ten. Current pretreatment costs are about 2¢/gal for ethanol from starch, and about 50¢/gal from cellulose. "Our aim is to reduce the pretreatment costs to 4–5¢/gal making cellulosic ethanol competitive with starch," says Atalla.

The cellulose from most pretreatment methods becomes a tight aggregate, which makes it difficult to hydrolyze or break down with enzymes, he explains. Our treatment, which involves washing the extracted cellulose with a water-ethanol solution of NaOH, produces a porous cellulose — a nanoscale sponge — that allows the 4–6-nm dia. enzymes to penetrate into the cellulose, explains Atalla.

Biobutanol

As plans for more commercial cellulosic ethanol plants continue, a number of startup companies and JVs are starting pilot plants for making cellulosic butanol. For one thing, butanol has a higher energy density than ethanol, which leads to a 25% higher fuel economy, says Taylor Ames, vice president and chief science and technology officer at Butamax Advanced Biofuels LLC (Wilmington, Del.; www.butamax.com) — a 50:50 JV of DuPont and BP established in 2009. Butanol also can be blended into gasoline at higher concentrations (in the U.S., 16 vol.% versus 10 vol.% for ethanol) and can be blended directly at petroleum refineries and transported via existing infrastructure, he adds.

Butamax has genetically engineered brewer's yeast to excrete *iso*-butanol instead of ethanol. The organ-

Name	Location	Capacity (million gal/yr)	Start-up	Name	Location	Capacity (million gal/yr)	Start-up
TABLE 2. PLANNED AND EXISTING CELLULOSIC ETHANOL PLANTS IN NORTH AMERICA (Continued)							
Ineos Bio	Vero Beach, Fla.	8	2011	Old Town Fuel & Fiber	Old Town, Maine	1.5	2011
POET	Emmetsburg, Iowa	25	2011	ICM	St. Joseph, Mo.	1.5	*
Powers Energy	Lake County, Ind.	32	2011	Iogen	Prince Albert, Sask.	18	2012
University of Florida	Gainesville, Fla.	0.13	2011	KL Energy	Kremmling, Colo.	5	*
Abengoa Bioenergy	York, Neb.	10	*	Mascoma	Kinross, Mich.	40	2013
Agresti Biofuels	Pike County, Ky.	20	2012	Pacific Ethanol	Boardman, Ore.	2.7	2012
American Energy Enterprises	New Milford, Conn.	24	*	Pan Gen Global	Colusa, Calif.	12.5	*
BlueFire Mecca	Palm Springs, Calif.	17	*	PureVision Technology	Fort Lupton, Colo.	2	*
Citrus Energy	Boca Raton, Fla.	4.	*	Raven Biofuels	Miss..	33	2013
Clemson University Restoration Institute	Charleston, S.C.	10	*	SunOpta Bioprocess/ Central Minnesota Ethanol Co-op	Little Falls, Minn.	10	2013

* Not available

Source: Biotechnology Industry Organization

ism is now ready for piloting later this year, says Ames.

Construction has started on a fully integrated piloting facility at BP's Hull Research Technology Center in the U.K. When the unit starts up later this fall, it will have a nominal capacity of 40,000 gal/yr of *iso*-butanol. The $50-million investment will be used to optimize the production process to achieve a cost of manufacturing equal to or less than ethanol for the same feedstock. In the beginning the plant will be grain based. Although any grains can be used in principle, we will focus on corn, says Ames. Full-scale commercial production is projected for 2012–2013.

Meanwhile, Gevo, Inc. (Englewood, Col.; www.gevo.com) secured a $1.8-million grant from the U.S. Departments of Energy and Agriculture's Biomass R&D Initiative to further the development of its yeast strains for making *iso*-butanol. Last September, the company started up a 1-million-gal/yr demonstration plant located at ICM, Inc.'s (Colwich, Kan.; www.icminc.com) St. Joseph, Mo. biofuels research center.

Gevo and ICM have a strategic alliance for the commercial development of Gevo's GIFT (Gevo Integrated Fermentation Technology) process that enables the production of *iso*-butanol and hydrocarbons from retrofitted ethanol plants. More recently, Gevo and Cargill, Inc. (Minneapolis, Minn.; www.cargill.com) established a licensing agreement giving Gevo exclusive rights to integrate Cargill's microorganisms into the GIFT process for making butanols from cellulosic sugars. Gevo anticipates full commercialization by 2011.

Taking a different approach, Cobalt Technologies (Mountain View, Calif.; www.cobaltfuels.com) is focusing its efforts on the production of *n*-butanol. Although it is somewhat less appealing as a fuel than *iso*-butanol due to a lower

TABLE 2. PLANNED AND EXISTING CELLULOSIC ETHANOL PLANTS IN NORTH AMERICA (Continued)							
Name	Location	Capacity (million gal/yr)	Start-up	Name	Location	Capacity (million gal/yr)	Start-up
Coskata, Inc.	Southeast, U.S.	55	2012				
DuPont Danisco Cel-lulosic Ethanol	*	15	2014	Terrabon	Bryan, Tex.	0.1	*
Enerkem	Pontotoc, Miss.	20	2012	U.S. Sugar	Clewiston, Fla.	100	2013
Enerkem	Edmonton, AB	9.5	2012	Vercipia	Highland Co., Fla.	36	2012
Genera (DDCE, UTenn.)	Tenn.	25	2012	West Biofuels	Yolo Co., Calif.	0.182	*

* Not available

Source: Biotechnology Industry Organization

octane number, *n*-butanol has many potential uses for making chemicals, says CEO Rick Wilson. "As a chemical, *n*-butanol sells for around $6/gal as opposed to $1.90/gal for fuel."

In January, Cobalt launched its first pilot-production facility, which has a 20 m.t./d hydrolysis unit and a fermentation reactor capable of producing 2–3 gal/d of butanol. We are on track to build a commercial facility within two years, says Wilson.

The process begins with a pretreatment step whereby wood is hydrolyzed in dilute acid and an acid promoter, which releases the sugars from the wood. Hydrolysis only takes a few minutes as opposed to days need by enzymes, he says.

After hydrolysis, the sugars are converted to *n*-butanol in a patented, continuous fermentation process. Instead of yeast used for making ethanol, or genetically modified yeast for making *iso*-butanol, Cobalt's process uses bacteria in biofilms on a support. Similar to a bioreactor used for wastewater treatment, the reactor continuously circulates the feed solution through the bioreactor. This continuous fermentation is about 30 times faster than batch fermentation. The system is controlled to remove product before the concentration becomes too high to poison the bacteria.

The *n*-butanol is then purified by a process involving both distillation and phase separation. The *n*-butanol/water solution is highly non-ideal, and simulations have been used to develop a separation process, which has several advantages. At low concentrations, the *n*-butanol comes off first. Secondly, the heat of vaporization is half that of ethanol, so less energy is needed for the distillation. Thirdly, a phase separation occurs at a certain concentration that allows us to bypass the azeotrope, so no molecular sieves are needed to achieve the final purity — another cost factor with ethanol, explains Wilson.

The company is focused on wood feedstock (both hardwoods and soft). Last month Cobalt announced its first butanol from beetle-killed pine wood.

"This is a very cheap feedstock — there's lots around and some even pay you to take it," he says. Colorado's pine forests have been devastated by mountain pine beetle, which has infested nearly half of the state's 5-million acres of pine forest. Cobalt is working with the Colorado State University for fuel testing. ∎

Gerald Ondrey

FOCUS ON
Pumps

This self-priming pump is available for water and wastewater processing

The Series 7000 mechanically actuated, diaphragm metering pumps (photo) can handle viscosities in excess of 5,000 cP and can pump chemicals that tend to off-gas (such as sodium hypochlorite) without binding. All models provide suction lift to 20 ft. Maximum capacities range from 15 to 300 gal/h with adjustble 10-to-1 turndown by micrometer dial. A variable speed option allows for automated flow control. Liquid ends are available in PVC, Kynar and 316 stainless steel. — *Neptune Chemical Pump Co., Lansdale, Pa.*
www.neptune1.com

This discharge pump ensures continuous flow of highly viscous fluids

The Cinox-V/Therminox-V stainless steel discharge pump (photo) is ideal for all plant operators with difficult applications at low inlet pressures (vacuum) and high levels of viscosity (up to 4 million mPas), such as resins, fats, silicones, sucrose esters and pre-polymers. It can be used at temperatures up to 350°C. The inlet geometry guarantees even filling of the gears at low pressure, ensuring continuous flow. Heated or unheated housings are available. A packing gland can be used, throttled and spring-loaded to prevent oxygen ingress. — *Maag Pump Systems AG, Oberglatt, Switzerland*
www.maag.com

Pump provides accurate delivery of chemicals during water treatment

The ability to accurately meter liquid sodium hypochlorite is challenging because of the fluid's tendency to outgas. The new Chloritrol system (photo) relies on a valveless duplex pump design to carry out the accurate injection of sodium and calcium hypochlorite during water purification. The first, high-pressure pump head injects sodium hypochlorite directly into the water main. The second pump head removes outgas bubbles from the inlet side of the high-pressure pump head.
 — *Fluid Metering, Syosset, N.Y.*
www.chloritrol.com
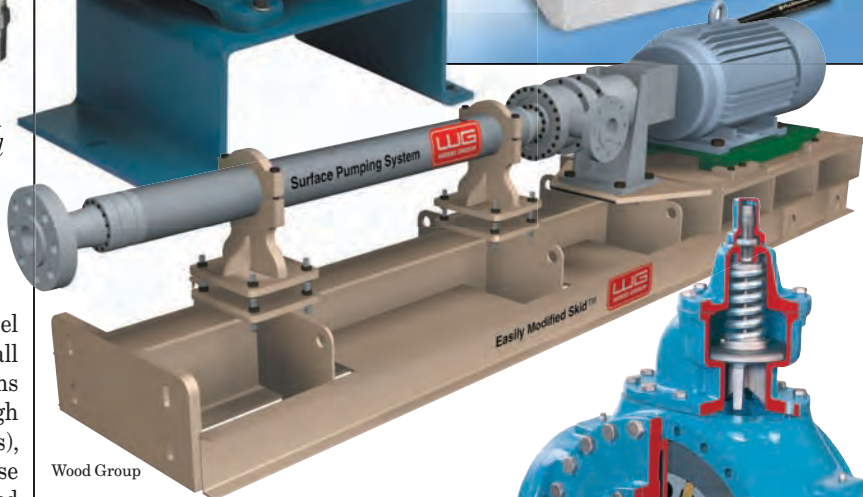
Wood Group

These surface pumps boast low maintenance and high reliability

The SPS Surface Pumping Systems (phoyod) feature a direct-coupled, multi-stage centrifugal design that is well-suited for most high-pressure, low- to medium-volume, environmentally sensitive applications. SPS pumps can handle flowrates up to 2,500 gal/min, at discharge pressures to 6,000 psi. The use of a single, low-pressure mechanical seal ensures reliability and reduces maintenance, while the ability to easily repair the units in the field increases operator flexibility. — *Wood Group, Oklahoma City, Okla.*
www.woodgroupsurfacepumps.com

Achieve fast product switchovers using this sliding-vane pump

The Model HXL sliding-vane pumps (photo) help process operators to quickly and efficiently evacuate product from large liquid storage terminals. These high-capacity pumps can handle large volumes of non-corrosive liquids, from thin solvents to heavy oils and molasses.
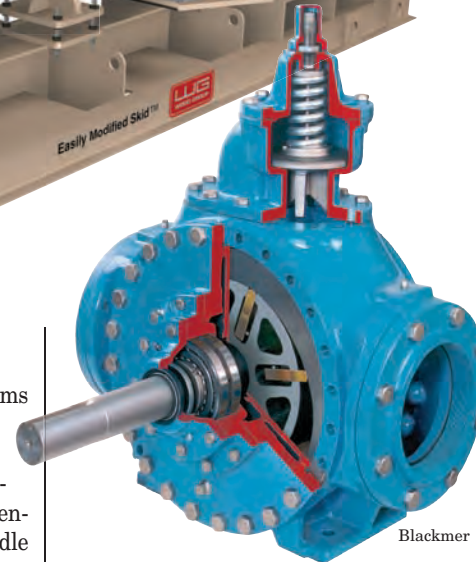
Blackmer

Strong suction-lift capabilities can efficiently transfer these products from barges or ships into tanks while efficiently stripping both suction and discharge lines to minimize product losses. Because they are self-priming, they are always ready to operate without the delays associated with priming routines, while an internal relief valve protects against excess line pressure. HXL models are available in 6-, 8-, and 10-in. ANSI flanged port sizes with operating speeds up to 350 rpm, and maximum rated capacities of 755, 1,228 and 2,300 rpm (172, 279, and 522 m^3/h). — *Blackmer, Grand Rapids, Mich.*
www.blackmer.com ∎
Suzanne Shelley

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

TLV's **TrapMan**® system is the world's first diagnostic instrument for steam traps with the capability to make a judgment of the trap's condition independent of the operator. And it's the only one that records both temperature and ultrasonic levels to measure leakage amount and valuate steam loss, thereby enabling expense allocation to ROI guidelines.

The operator needs only to place the probe against the trap for 15 seconds—the TM5 portable data collection and measurement instrument performs the analysis automatically. It compares the measurements against empirical test data on 2,960 trap models and the handheld TM5 can store 1,600 individual tests. Its powerful database software is compatible with Windows 98/NT4.0(SP6)/2000/XP PC for detailed analysis and reporting.

Call **TLV** to learn more about productivity, reliability, and energy efficiency benefits for your site.

Manage Your Steam Trap Population

WHO'S WHO

| Bellamy | Quasey | Hancook | Johnson | Hayes |

Michael Bellamy is appointed general manager of the PII Pipeline Solutions business of **GE Oil & Gas** (Northumberland, U.K.).

Jim Quasey is named vice-president of global operations for **Industrial Scientific Corp.** (Pittsburgh, Pa.).

Kim Holman joins **Total Safety** (Houston) as area manager, Canada.

EagleBurgmann USA (Houston) names *Emery Johnson* dry-gas-seal sales manager for North America.

Mitchell Anderson is named director of operations at **Groth Corp.** (Stafford, Tex.), a maker of relief valves and flame arrestors.

Khadem Al Qubaisi, managing director of the International Petroleum Investment Co., becomes chairman of the supervisory board for plastics maker **Borealis AG** (Vienna).

Eplan Software & Services (Farmington Hills, Mich.) names *Jan Dominik Gunkel* president of the company's North American operations.

Mary Ann (M.A.) Hancook becomes director of marketing and communications for specialty chemical supplier **Viachem Ltd.** (Plano, Tex.).

Jim Hayes is named commercial director for the construction industry, Americas region, for **Dow Corning** (Midland, Mich.).

Simon Upfill-Brown becomes COO of **Terrabon** (Houston), a provider of waste-to-fuel conversion systems. ■
Suzanne Shelley

Parker Hannifin

MAY
New Products

Get on-demand nitrogen with these generators

The latest version of the Midigas (photo) and Maxigas onsite nitrogen generators are available now for a wide range of applications, including modified atmosphere packaging, purging, blanketing and pressure transfer. The on-demand nitrogen generators produce nitrogen from compressed air onsite and offer an alternative to traditional nitrogen gas storage cylinders or bulk storage equipment. Midigas, designed for small- to medium-nitrogen requirements, and Maxigas, for medium to large needs, can offer significant savings in nitrogen costs, with equipment payback in 12–24 months, and ongoing savings of up to 90%, says the manufacturer. The systems produce nitrogen according to the demands of downstream processes, which limits waste and reduces overall energy consumption. — *Parker Hannifin Ltd., Industrial Division, Birtley, U.K.*
www.parker.com

Simultaneously detect five elements with this flame photometer

The XP Flame Photometer (photo) detects and displays concentrations of sodium, potassium, lithium, calcium and barium simultaneously in liquid samples. The instrument measures characteristic wavelength emissions for the five elements and calculates concentration based on emission intensity. The XP photometer can be used with multiple fuels, including propane, butane, natural gas and liquified petroleum gas, and has a flameout and automatic shutdown feature for safety. It is configured to be compatible with centralized or local computer networks, and comes with all equipment necessary for calibration, including calibration standards. — *BWB Technologies, Essex, U.K.*
www.bwbtech.com
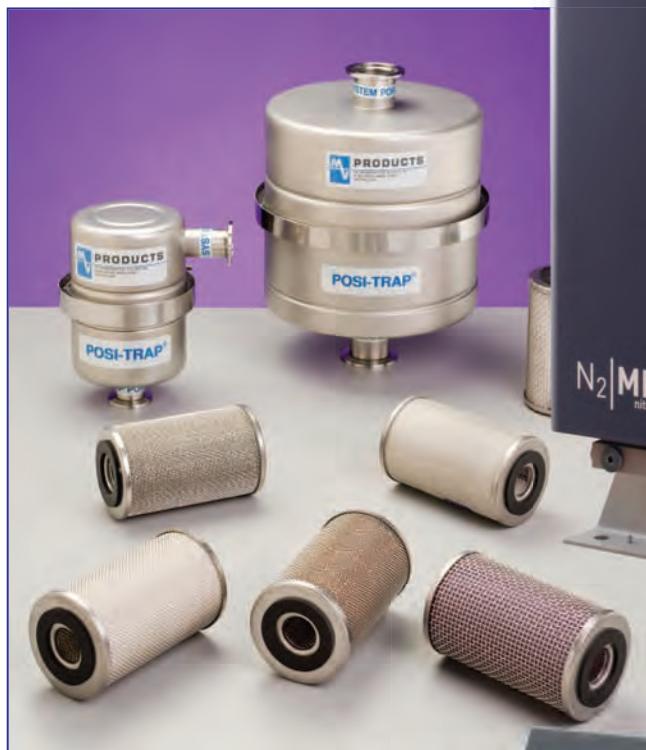
MV Products

This pump inlet trap is adaptable to changing processes

The PosiTrap Vacuum Inlet Trap product line (photo) is designed to protect pumps in small production and R&D applications up to 50 ft^3/min. The filter elements are available in a variety of specialized media that are easily changed to allow tailoring to different processes. The user-selectable elements remove corrosive and abrasive particles from the vacuum stream to protect vacuum pumps. The filter elements are positively sealed at both ends to prevent "blow-by" and come in 4- and 8-in.-dia. straight-through and right-angle models. Filter types include stainless-steel-and-copper gauze, molecular sieve, activated charcoal and pleated polypropylene. — *MV Products Inc., Mass-Vac division, North Billerica, Mass.*
www.massvac.com

BWB Technologies

A chlorine dioxide analyzer with automatic flow control

The CDA-22 chlorine dioxide analyzer (photo, p. 32D-2) monitors ClO_2 concentrations from 0.05–20 ppm. Featuring a panel-mounted plumb-and-play design and automatic flow control, the

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

CHEMICAL ENGINEERING   WWW.CHE.COM   MAY 2010   **32D-1**

New Products

Electrochemical Devices

CDA-22 is suitable for measurement of chlorine dioxide concentrations in industrial cooling and rinse water, wastewater, municipal water and other fresh water samples. Designed for easy installation and maintenance, the CDA-22 incorporates an automated flow control device and a controller mounted on a PVC panel. — *Electrochemical Devices Inc., Yorba Linda, Calif.* **www.ecdi.com**
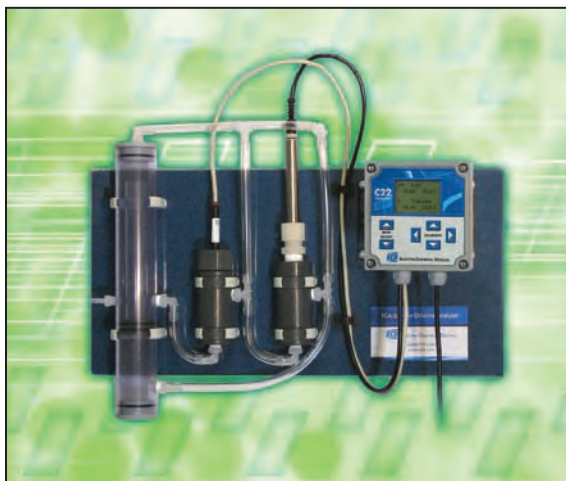
This dessicant dryer is designed for small applications

KADW products are wall-mounted dessicant dryers with capacities from 7 to 50 ft³/min at 100 psig. They are capable of delivering consistent dew points as low as 100 °F and are designed for easy installation. The instruments feature an accurate steady-state timer and are based on a counter-flow design that ensures the driest dessicant material is always at the top of the bed. They are available fully assembled in ready-to-mount cabinets. — *Kaeser Compressors Inc., Fredericksburg, Va.* **www.kaeser.com**

Direct or converge solids with this diverter

The Quantum Series four-way, wyeline diverter can direct powder, pellets or granules from one source to four destinations or converge from four sources to one destination. It is engineered to handle dry bulk solids in pneumatic conveying systems with vacuum or positive pressures up to 15 psig. Available in 2–6-in. pipe or tube, the diverter can be constructed of stainless steel, aluminum and/or carbon steel. The diverter can also be customized with a wide selection of actuators, position indication switches, flanges and tube stubs, as well as modified to accommodate high or low temperatures, corrosive, humid and hazardous environments. — *Vortex Valves North America, Salina, Kan.* **www.vortexvalves.com**

Measure density directly with this online meter

The Liquiphant M density meter (photo) provides direct, online measurement of density and concentration, thus eliminating the need for offline laboratory instruments. The online measurements allow control systems to react more rapidly to changing process conditions. Equipped with a mechanically oscillating fork that is excited to its resonant frequency, the Liquiphant M is immersed in process liquid, which changes its frequency. Those changes are related to the density of the medium. Applications suitable for the Liquiphant M include: content measurements, quality statements, purity indication and product identification. — *Endress+Hauser Inc., Greenwood, Ind.* **www.us.endress.com**

This catalyst is designed for high-melt-flow applications

The D7000 Donor catalyst is designed specifically to optimize high-melt impact copolymer polypropylene resins, such as the plastic used in automotive interior and food contact applications. The catalyst is said to smooth and speed transitions between product grades and improve performance characteristics of finished products. In addition, the catalyst allows the reduced use of peroxide, which lowers resin manufacturing costs. Commercial trials with the catalyst have shown improved process efficiency and lower costs, says the manufacturer. — *Dow Chemical Co., Midland, Mich.* **www.dow.com**

Pulsafeeder
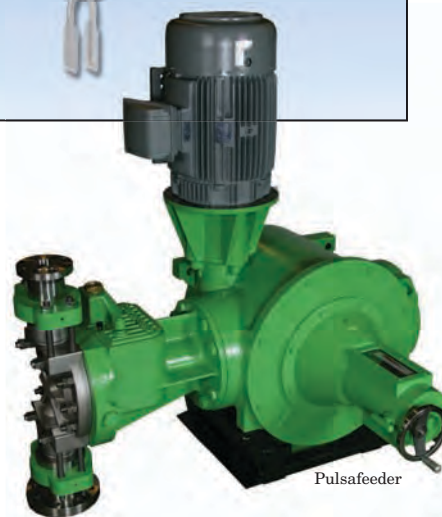
Motors for this versatile pump can be mounted horizontally or vertically

The PulsaPro 900, a hydraulic diaphragm process and metering pump (photo), is designed for a broad array of chemical, petrochemical and oil-and-gas applications. It can handle flows to 16,380 gal/h (62,000 L/h), standard pressures to 4,350 psi (300 bar), and future design capabilities to 15,000 psi (1,000 bar). This pump can handle process temperatures from –100°F (–73°C) to 500°F (260°C) with standard viscosities to 3,000 cp. The patented hydraulic diagnostic package both protects the pump from damaging operation forces and presents a visual indication of pump performance. — *Pulsafeeder, Rochester, N.Y.* **www.pulsafeeder.com**

Economically measure product from bags

The Aero-flex flexible screw conveyor provides an economic method of metering product from bulk bag unloaders, bag dump stations and storage vessels. Available in a range of sizes, the conveyor transfers powders over distances of up to 40 ft and rates to 10 ton/h for

Radio Frequency

materials having a bulk density of 40 lb/ft^3. Applications include the refilling of packaging machine hoppers, metered feed into mix tanks and gain-in-weight hopper filling and bulk bag discharging. — *Vac-U-Max, Belleville, N.J.* **www.vac-u-max.com**

Save time and expense with this new drying system
The Macrowave radio frequency (RF) drying system heats filter cake material uniformly to remove water without overheating. The drying system is a suitable replacement for tumble, spray, tray, spin flash and belt/tunnel dryers, and can reduce labor and energy costs by up to 60%, according to the manufacturer. The Macrowave applies energy to filter cake material in the form of RF waves at a frequency of 40.68 MHz. The equipment features volumetric heating, which provides rapid and uniform heating to prevent overheating. The system is available in both batch and conveyorized configurations. — *Radio Frequency Co. Inc., Millis, Mass.* **www.radiofrequency.com**

This sifter features quick screen changes
The Kek Centrifugal Sifter offers efficient processing of powders, granules and slurries, and allows rapid screen changes — under 30 seconds in most cases — and easy access for cleaning. It is available for gravity and fully in-line pneumatic conveying applications with output ranges from a few pounds per hour to over 100,000 lb/h. The Kek Centrifugal Sifter provides size classification for a variety of applications including: de-agglomeration, bulk conditioning, classification, scalping, inline sifting, policing raw material, dedusting, dewatering and reclaiming damaged product. It is compact, dust-tight, vibration-free and virtually noise-free. — *Kemutec, Bristol, Pa.* **www.KemutecUSA.com**

Manage GHG reporting with this package
This greenhouse-gas-(GHG) reporting startup package is designed to help companies quickly set up the calculations, data collection and quality control and assurance processes that are necessary for important source categories of the U.S. Environmental

Lenox Instrument

Griswold Pump

Agency's mandatory GHG reporting rule. The GHG Quick-Start Package includes templates for data collection, emissions accounting, calculation processes and more. The GHG reporting package is part of a more comprehensive GHG management solution from this company. — *TechniData America LLC, Wilmington, Del.*
www.technidata.com

Monitor combustion flames in realtime with this camera

The FireSight Thermal Imaging Camera System (photo) can provide clear, realtime monitoring of furnace and boiler flames, as well as accurate, non-contact temperature measurement. Designed to be installed through a small opening in the combustion chamber wall, the high-resolution camera and lens tube employ efficient water-cooling and integrated air-purging to keep the optics free of debris. The infrared camera operates within a wavelength band carefully selected to eliminate obscuring and measurement errors caused by absorption and emission bands present in the combustion gases in hydrocarbon-fueled furnaces, boilers and fired heaters. The camera can be remotely controlled by image-processing software, which is included. — *Lenox Instrument Co., Trevose, Pa.*
www.lenoxinst.com

Enclose the entire noise source to meet OSHA noise specs.

Soundscreen panels and equipment enclosures provide thermal and acoustical control for blowers, fans, compressors, pumps and other bulk handling equipment. By enclosing the entire noise source, noise levels can be reduced to within OSHA specifications, typically 20–25 dB. The outer shell construction is solid galvanized steel with acoustical and thermal fiberglass batt (pre-cut panels) insulation fill and either a solid or perforated inner liner of galvanized steel. The fiberglass insulation will not settle or promote the growth of bacteria, mold, vermin or insects. Soundscreen panels are available in durable 2- and 4-in.-thick panel constructions with maintenance access and ventilation, and are suited for indoor or outdoor applications. — *McGill AirSilence LLC, Columbus, Ohio*
www.mcgillairsilence.com.

Clean 'on the fly' with this drawer magnet

The HF Series drawer magnets are equipped with powerful magnetic cartridges to handle a wide range of separation tasks in mechanical or gravity flow applications. The cartridges can fully extend outside the housing, and clean "on-the-fly," with no disruption of product flow. As the tube assemblies travel outside the housing, grommets wipe the tubes clean all the way to their nonmagnetic tapered ends Cartridges in the HF Series can be configured with two or more trays in a staggered arrangement to increase contact with the product stream. The equipment is available in utility, powder, food and sanitary construction grades and in a standard two-row model and three- and four-row trays as well. — *Bunting Magnetics Co., Newton, Mass.*
www.buntingmagnetics.com

This pump is ideal for corrosive, abrasive, solid and fibrous materials

The open impeller design of 811 ANSI Series pumps (photo) provides performance advantages during the pumping of demanding chemical process fluids. For instance, the open impeller minimizes concentrated wear by balancing the hydraulic axial thrust load. It also reduces stuffing-box pressure, simplifies maintenance, extends pump life and reduces repair costs, says the company. These self-tightening impellers also help to reduce leakage and failure. — *Griswold Pump Co., Grand Terrace, Calif.*
www.griswoldpump.com

Versatility is the major feature of these rupture disc holders

The TQ+ is a new pre-torqueable rupture disc holder in this company's product line. The TQ+ type was designed to be installed in multiple international flange rating configurations, including ANSI, JIS, DIN and ISO, making the rupture-disc holders versatile enough to be used in a wide range of applications. Pre-torqueable holders allow rupture discs to be installed, then torqued to recommend static load levels, properly clamping the rupture disc within the assembly. The holders have the ability to be removed, inspected and re-installed during routine maintenance. — *Fike, Blue Springs, Mo.*
www.fike.com

A new version of a popular ball-valve actuator improves quality

An updated version of the Series 83A Electromni actuator for small, quarter-turn ball valves is available from this company. Designed for improved performance, the Series 83A now features a Nema 4X-type enclosure to meet today's industry standards. The flanged cover and baseplate design with a full gasket Nitrile seal enhances sealing performance to keep external water out of the actuator enclosure. The new version now has four captivated 304 stainless-steel, hex-head-slotted cap-screws to fasten the actuator's cover and base halves together, and four Nitrile cap-plugs to cover the for-

Asahi/America

merly exposed motor mounting bolts. Dimensions permit tight fits and incoming customer wiring hook-up requirements remain unchanged from previous versions of the actuator. — *Asahi/America Inc., Malden, Mass.* **www.asahi-america.com**

This probe offers continuous monitoring of particles

The Parsum inline particle probe features the particle velocimetry technique for inline particle-size measurement. The technique is suitable for measuring particles in the size range from 50 to 6,000 µm travelling at velocities of between 0.01 and 50 m/s. The size and velocity ranges make the technique ideal for monitoring processes such as granulation, spray drying, fluidized bed and particle size reduction. — *Malvern Instruments Inc., Westborough, Mass.* **www.malvern.com**

Reduce heat loss by 49% with this insulation

Hitlin (high-temperature layered insulation) features low thermal conductivity that offers 49% less heat loss than traditional industrial insulation materials calcium silicate and perlite, according to the manufacturer. The new industrial insulation is appropriate for power plants, petroleum refineries and petrochemical plants, among others, and can be used in process applications with temperatures up to 1,400°F. Hitlin is made of continuous filament E-glass fibers that are bound through an enhanced mechanical needle-punching process, then mandrel-wound into pipe cover sizes from 0.5- to 44-in.-

New Products

dia., and thicknesses up to 6 in. Said to have total installed costs and life-cycle costs lower than competing products, Hitlin is now being distributed in North America. — *Visionary Industrial Insulation, Kapolei, Hawaii* **www.hitlinusa.com**

Handle heavy slurries with this knife gate valve
Designed especially for heavy slurry applications in the power and mining industries, the Series DX slurry knife-gate valve minimizes wear by reducing turbulence with reinforced elastomer sleeves that provide a 100% full port opening. The valve can provide drop-tight shut-off in both directions. The Series DX design also prevents slurry build-up in the seat by discharging a small amount of slurry from the valve to keep the gate path and seat area clear of entrapped particulate material. — *Red Valve Co. Inc., Carnegie, Pa.* **www.redvalve.com**

This polymer is designed for fuel contact applications
Fuel'In is a new family of polyamide 6 and 6,6 polymers designed specifically for fuel contact, including fuel storage and transport. The polymer family provides high barrier performance and up to 30% weight reduction without compromising safety. The polymer line has proven durability and high impact resistance, even at low temperatures, says the company, and offers users reduced processing costs through minimal tooling and machine investment. — *Rhodia S.A., Lyon, France* **www.rhodia.com**

Laboratory applications will benefit from this tiny, automated pump
This company's Asia Syringe Pump (photo) is only 23 cm wide, yet is rated to 20 bar (300 psi). Constructed from highly chemically resistant poly-tetraflurorethylene (or other fluori-

nated polymers) and glass, this pump is well-suited for laboratory use. The compact module offers two independent continuous flow channels, each with an integrated pressure sensor and a flowrate range from 0.01 to 10 mL/min. The flowrate and volume can be controlled using the intuitive front panel, or via the firm's Asia PC software. — *Syrris, Royston, U.K.* **www.syrris.com**

Moyno

Magnetic-drive pump provides a 'zero-leakage' option for operators

The Moyno Mag Drive 500 Series pumps (photo) are said to be the first progessing-cavity, wobble-stator pumps to offer magnetic drives. They are designed to handle toxic, aggressive, caustic or even flammable and explosive fluids. This proprietary mag-drive pump is designed to maximize operator safety, eliminate workplace hazards and protect the environment by eliminating leakage pathways. The elimination of mechanical seals also helps to eliminate costly repairs. Four models are available, providing flowrates from 0.1 to 900 gal/h. — *Moyno, Inc., Springfield, Ohio*
www.moyno.com

This incremental encoder can handle harsh environments

The Sendix 5006 2-in. incremental encoder features a completely stainless-steel housing and Viton seals to resist corrosion and physical abuse in harsh plant environments. The encoder can handle fluctuations in temperature, from –40 to 85°C, and is IP67-rated when sealed. The Sendix 5006 incorporates a proprietary Safety-Lock bearing assembly that has been tested to provide additional protection against vibration and installation errors. It is ideal for use in corrosive environments or for applications requiring long-term durability. — *Turck Inc., Plymouth, Minn.*
www.turck.us

Deposit low-friction coatings with this system

The AL400 system is a new plasma-enhanced, chemical-vapor-deposition (PECVD) instrument designed for the deposition of a smooth coating on rubber and elastomeric surfaces. The low-coefficient-of-friction coating reduces tackiness and drag of rubber and elastomeric surfaces, and can repel lint and other contaminants on silicone components. Coating thickness is typically less than one micron, and has no effect on the bulk properties of the coated material. The PECVD system is clean-room compatible and available in a table-top version or with a free-standing enclosure. — *Plasmatech Inc., Erlanger, Ky.*
www.plasmatechnology.com

This sifter allows quick screen changeouts

The CS-1 gyratory sifter is a stacked-deck sifter designed to save time and labor in screen changes. Screen inserts can be switched within minutes using only standard hand tools, without the need for glues or tensioning machines. The CS-1 provides two to four separations of dry product from ¼ in. size down to 400 mesh with a capacity of 50,000 lb/h. — *Sifter Parts and Service Inc., Wesley Chapel, Fla.*
www.sifterparts.com

Protect sensitive instruments with this gas cylinder

The Ecocyl OSQ specialty gas cylinder uses a unique form of negative gas pressure to protect sensitive instruments, such as environmental monitoring devices, from damage due to positive gas pressure, which can be associated with conventional gas cylinders. The on-demand, stainless-steel cylinder is refillable, and has an integrated cylinder valve, pressure regulator and flow control device, which are permanently protected by a specially designed protective cowling. The new cylinder is suited to instruments such

New Products

as detection monitors with integrated pumps or monitors calibrated in docking stations with built-in pumping systems. — *Linde Canada Limited, Mississauga, Ontario, Canada*
www.lindecanada.com

This pump family is designed for sanitary and hygienic applications

Pro-Flo X Hygienic Series pumps feature the company's patent-pending Pro-Flo X Air Distribution System (ADS) and the Efficiency Management System (EMS). The ADS provides reliable operation, high flowrates, and anti-freezing characterisics, while the EMS allows the user to control flowrate and efficiency with the turn of a dial. All polished product-contact surfaces have a maximum roughness values (Ra) of 0.8 μm. A flow-through liquid chamber design and smooth flow path enhances cleanability and prevents product entrapment. — *Wilden Pump, Grand Terrace, Calif.*
www.wildenpump.com

These compact pumps are ideal for applications with space restrictions

The three-chambered configuration of the Flojet Triplex Series high-pressure, self-priming pump operates at flowrates up to 1.4 gal/min (5.3 L/min) and operating pressures up to 150 psi (10.3 bar). Their molded diaphragms virtually eliminate potential leakage paths, says the company. These pumps can run dry for extended periods without damage. — *ITT Flojet, SantaAna, Calif.*
www.flojet.com

Seal-less centrifugal pumps keep potential emissions at bay

The Series NMWR seal-less centrifugal pumps (photo) have magnetic couplings and no shaft duct to the atmosphere, and are available with maximum capacity to 4,000 gal/min and differential head to 500 ft. The containmment shell forms a closed system with a hermetically sealed liquid end. They are designed to handle heat transfer fluids with temperatures up to 750°F without cooling. The containment shell provides a simpler replacement to conventional double-acting mechanical seals with external fluid reservoirs, says the firm. — *Dickow Pump Co., Marietta, Ga.*
www.dickow.com
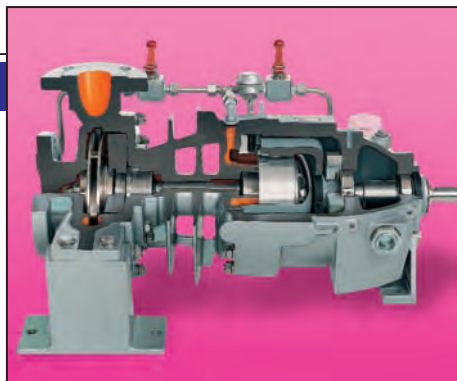
Less pipe straight-run needed with this flow conditioner

The Model VIP flow conditioner offers this company's tab-type flow-conditioning technology in a low-cost, simply installed insertion panel format. It avoids the need, as with many flowmeter types, to have a significant straight run of pipe to allow a repeatable, swirl-free flow profile to the sensor. When space and pipe orientation conditions do not allow a straight run, the VIP can neutralize flow disturbance from valves, elbows and other components when installed at a distance of three pipe diameters from the flow meter, allowing optimum function of the flowmeter. The thin, lightweight VIP can be installed between flanges or welded in place. — *Vortab Co., San Marcos, Calif.*
www.vortab.com

New rules in vacuum drying: The Planex System

The Planex System (photo) is a new horizontal paddle vacuum dryer developed for vacuum drying of wet powders obtained from centrifuge or filter press. The system consists of a fixed cylindrical chamber with an eccentric agitator inside with two independent movements: it can rotate on its own axis and tangentially to the cylindrical chamber as well. This combined double rotation allows optimal product mixing, continuously renewing the surface exposed to evaporation. As a result, the release of solvent vapor is facilitated and drying times are significantly reduced compared to conventional systems, says the manufacturer. The unique configuration of the agitator and the double rotation provides continuous revolution of the product while limiting the mechanical and thermal stress, preventing local overheating due to friction. The mechanical stress on the product is said to be three times less than that produced in traditional paddle dryers

Italvacuum

equipped with concentric agitators. This property makes the system ideal for drying heat-sensitive products, and also leads to a reduction in power consumption by about a third. — *Italvacuum S.r.l., Borgaro (Torino), Italy*
www.italvacuum.com

Eccentric-disk pumps can be used for abrasive, thick or thin fluids

The Mouvex SLC-Series eccentric-disk pumps are designed to self-compensate for mechanical wear and maintain consistent flow over time. With seal-less construction, low shear and agitation of the pumped product, the ability to run dry for up to five minutes and clean-in-place capabilities, these pumps enjoy lower maintenance requirements and lifecycle costs for the transfer of various liquids. The eccentric-disk technology produces the pumping performance of a positive-displacement pump, creating a constant flow independent of pressure and viscosity, says the firm. — *Mouvex, Auxerre, France*
www.mouvex.com

This pump family has been expanded to include an engine-driven model

The newest addition to the Ultra V Series pumps family is an engine-driven model said to offer higher pressure, flow and efficiency than comparable pumps. Shimless adjusting, atmospheric vents and self-cleaning wear plates ease maintenance requirements. They are available in 3-, 4- and 6-in. sizes, and can handle flows of 2,050 gal/min and maximum head of 175 ft. — *Gorman-Rupp, Mansfield, Ohio*
www.gormanrupp.com ∎

Scott Jenkins

CHEMICAL ENGINEERING
FACTS AT YOUR FINGERTIPS
Department Editor: Scott Jenkins

Burner Operating Characteristics*

Burners are critical for the successful operation of industrial furnaces. Presented here is a set of equations that can be used to calculate characteristics of burner operation, including flame length, flame diameter, ignitability and flameout conditions. Equations are based on pre-mix burners operating at atmospheric pressure and firing natural gas only. Premix burners create short and compact flames compared to raw gas burners, and are designed to function with fuel-gas mixtures that have consistent specific gravity and composition.

Burner requirements
For direct-fired heaters to function correctly, burners must be capable of providing sufficient heat liberation from the fuel to meet heater processing requirements — based on the lower heating value (LHV) of the fuel. A fuel's LHV can be defined as the amount of heat produced by combusting a specified volume, and returning the combustion products to 150°C. For the heater to operate at the design process flowrate, the burners need to provide the heat necessary to maintain process fluid temperature and meet vaporization requirements at the heating coil outlet.
- The number, size and placement of burners must allow each coil to operate at the same design outlet temperature
- Design tube-metal temperature cannot be exceeded at any point on the coils
- Burner size must allow an outlet velocity that does not result in malfunction over the range of flow conditions
- Burner flame length should be less than firebox height (for vertical cylindrical heaters) or less than firebox length (for end-wall-fired heaters)
- Excessive flame height and diameter should be avoided to prevent flame impingement on tubes
- Burner spacing should be sufficient to allow burner-to-burner, as well as burner-to-tube clearance

The following equations can help establish optimal burner diameter:

$$\frac{Q_{lib\,heater}}{N_b} = 0.785 D_b^2 V_b C_{fuel} 3{,}600 \frac{(LHV)}{C_{air+fuel} SV_{fuel}} \quad (1)$$

$$\frac{0.785 D_b^2 V_b}{SV_{fuel+air}} = \frac{0.785 D_f^2 V_b}{SV_{flame}} \quad (2)$$

$$D_{f\,max} = \left(\frac{SV_{flame}}{SV_{fuel+air}}\right)^{0.5} D_b \quad (3)$$

$$0.785 D_b^2 V_b = 3.14 \frac{D_b L_f V_f}{2} \quad (4)$$

Burner clearance
Establishing burner-to-burner clearance and burner spacing should be based on maximum burner flame diameter. Further, burner flame diameter should be evaluated at maximum burner-flame length. Sufficient burner-to-burner, outside diameter clearance should take into account the placement of structural elements between burners.

Sufficient burner-to-burner clearance prevents interference between the flame bodies and unburned fuel cores generated by adjacent burners, which results in the absence of unburned fuel within the burner flame when maximum flame length is reached. Burner center-to-center spacing should be at least one fully combusted flame diameter.

Clearance between the burner-flame (at maximum diameter) and the outside diameter of tubular heating surfaces should be set such that burner-to-tube flame impingement is avoided. Doing so will prevent tube damage due to overheating and will make best use of heating surfaces.

Flameout
At high burner velocities, flame loss can occur if the heat gain due to burner ignition is less than the heat loss from the burner flame. Burner velocities may be pushed well above that used in normal heater operation in an effort to achieve higher heater capacity. Aside from flame loss while the heater is in operation, flameout can also be characterized by difficulty maintaining a stable flame at startup, or an inability to ignite the burner. The following equations can help predict the circumstances under which flameout conditions might occur:

$$Q_{gain} = \frac{A_s V_f C_{fuel}(LHV)3{,}600}{C_{air+fuel} SV_{fuel}} \quad (5)$$

$$Q_{loss} = (HTC)_c A_s (T_{flame} - T_{surr}) \quad (6)$$

$$(HTC)_c = 0.3(T_{flame} - T_{surr}) \quad (7)$$

$$(HTC)_f = 0.0144 \frac{G^{0.8}(C_{p\,surr})}{D_b^{0.2}} \quad (8)$$

$$(HTC)_r = 0.173 E_g \frac{\left[(0.01 T_{flame})^4 - (0.01 T_{surr})^4\right]}{(T_{flame} - 540 R)} \quad (9)$$

NOMENCLATURE

$Q_{lib\,heater}$	=	Heater liberation, Btu/h
N_b	=	Number of burners
D_b	=	Burner diameter, ft
V_b	=	Burner exit velocity, ft/s
C_{fuel}	=	Fuel, ft³
LHV	=	Lower heating value of fuel, Btu/lb
$C_{air+fuel}$	=	Volume of air and fuel mixture, ft³
SV_{fuel}	=	Specific volume of fuel, ft³/lb
$D_{f\,max}$	=	Maximum flame diameter, ft
L_f	=	Flame length, ft
SV_{flame}	=	Specific volume of flame, ft³/lb
V_f	=	Flame propagation velocity, ft/s
Q_{gain}	=	Burner heat gain, Btu/h
Q_{loss}	=	Burner heat loss, Btu/h
A_s	=	Flame front area, ft²
$(HTC)_c$ $(HTC)_f$, $(HTC)_r$	=	Natural convective, forced-convective, and radiative heat transfer coefficients, respectively, Btu/h-ft²-°F
T_{flame}	=	Flame temperature, R
T_{surr}	=	Surrounding temperature, R
E_g	=	Flame emissivity
C_p	=	Gas specific heat, Btu/lb-°F
A	=	Frequency factor in the Arrhenius equation
H	=	Heat of activation, Btu/lb-mol R
R	=	Gas constant, 1.987 Btu/lb-mol R
T	=	Gas Temperature, R
dC_m/dt	=	Fuel concentration change, mol per ft³/s
K	=	Reaction velocity constant, s⁻¹
W_f	=	Fuel, lb/h

Flame velocity
The heat generated by combustion is dependent on the flame propagation velocity. In a situation with 0% excess air, the ratio of fuel-to-fuel+air is about 0.1. In that case, evaluation of the flame propagation velocity is straightforward. However, at fuel-to-fuel+air ratios higher or lower than 0.1, it is more difficult. The following equations can help predict flame propagation velocity in those cases:

$$K = Ae^{-H/RT} \quad (10)$$

$$\frac{-dC_m}{dt} = K(C_m) \quad (11)$$

$$W_f(LHV) = W_{air+fuel} C_{p\,average}(T_{flame} - 60^o F) \quad (12)$$

References
1. Cross, A., Fired-Heater Burner Performance, *Chem. Eng.*, April 2008, pp. 44–47.

*The text was adapted from the article "Fired-Heater Burner Performance," by Alan Cross. It appeared in the April 2008 issue of *Chemical Engineering*.

Hydrogen Production By Steam Reforming

Management of the gas is critical for petroleum refiners

Ray Elshout
Energy Systems Engineering

Steam reforming of natural gas at petroleum refining facilities is the predominant means of producing hydrogen in the chemical process industries (CPI). Areas where hydrogen is heavily consumed include ammonia production, the cryogenics industry and methanol production (Table 1)[1]. Because hydrogen needs within various sectors of the CPI are at their highest levels in history, and are continuing to grow, an understanding of this method of hydrogen production and purification can be useful.

A major percentage of hydrogen used in the CPI goes toward production of ammonia, which continues find greater demand in the chemical fertilizer industry. On the other hand, methanol usage is declining in connection with its use as a feedstock for making methyl *tert*-butyl ether (MTBE; by reaction of methanol with tertiary butylene). In the U.S., MTBE had been used as a gasoline blend stock until recently, when use of the chemical as a gasoline oxygenate was phased out in favor of ethanol.

In addition to being producers of hydrogen, largely through steam reforming, petroleum refineries are also large consumers of the gas (for more, see pp. 21–24). Consumption of hydrogen by petroleum refineries has increased recently due to clean-fuels programs, which require refiners to produce low-sulfur gasoline and ultralow-sulfur
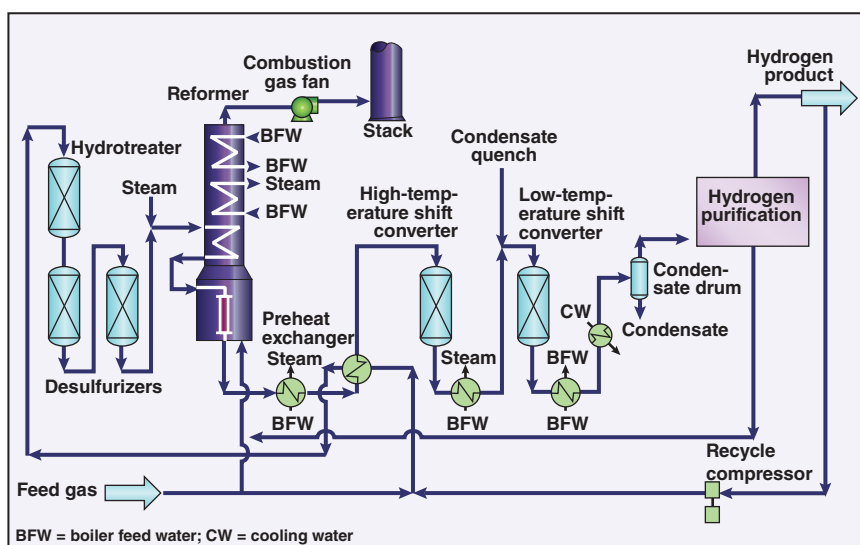
FIGURE 1. Steam-methane reforming is still responsible for the bulk of hydrogen production in petroleum refineries

diesel fuel. Management of hydrogen is a critical concern for refiners because various processes require different hydrogen pressure levels and purity.

Hydrogen-using processes that require high pressures and high purity, including hydrocracking, use hydrogen above the 100 kg/cm^2 (1,500 psig) level. When a recycle gas system is used, the higher pressures are needed to maintain hydrogen partial pressure at the desired level as methane concentration in the hydrogen feed to a hydrocracker increases. Sufficient hydrogen partial pressure promotes the intended reactions without producing undesirable coke.

If the hydrogen partial pressure cannot be maintained, the recycle gas should be bled. With pressure swing adsorption (PSA) processes producing hydrogen of purity in the range of four-nines (99.99%), this is not a problem.

Other hydrogen users, like those engaging in milder hydrotreating, can use lower-purity hydrogen at lower pressures (600 psig or lower). One approach that makes sense is recovering hydrogen from the users requiring higher pressure and reusing it at the lower pressure levels.

Minimizing the hydrogen bled into the fuel gas can keep the hydrogen production levels manageable. However, the hydrogen plant feed usually includes some hydrogen that goes through for a "free ride," except for the cost of heating it up to reformer temperature and ultimately cooling it back down to recovery level.

A recently employed practice in the industry is for the hydrogen to be produced for adjacent producers and sold to the user as "over-the-fence" hydrogen. This keeps the production costs off the books from the adjacent user and has found popularity not only in the U.S. but also in Europe.

STEAM-METHANE REFORMING

Refinery hydrogen comes primarily from two sources — catalytic reforming of byproduct gas from the dehydrogenation of naphthenes into aromatics and high-octane gasoline blend stocks,

TABLE 1. HYDROGEN USAGE BY INDUSTRY		
Hydrogen final usage category	Usage by industry (%)	Comments
Ammonia	37	An ammonia plant is typically a hydrogen plant with a second converter that reacts hydrogen with nitrogen
Merchant	3	This includes all bottled users, liquid hydrogen supplied in tank trucks, and gaseous hydrogen in short pipe lines (not including the over-the-fence hydrogen suppliers)
Methanol	10	
Refinery hydrogenation	19	Hydrocracking and hydrotreating
Cryogenics	17	
Refinery fuel gas	14	Last resort

as well as from direct hydrogen manufacture. The bulk of direct hydrogen manufacturing in a petroleum refinery is still accomplished via either steam-methane reforming (Figure 1) or steam-naphtha reforming. Partial oxidation of heavier hydrocarbons is also used to a limited extent.

In the overall steam methane reforming (SMR) reaction, methane reacts with steam at high temperatures and moderate pressures in catalyst-filled tubes to generate synthesis gas, a mixture of hydrogen, carbon monoxide and some carbon dioxide.

The reactions for the two simultaneous SMR mechanisms are shown as Equations (1) and (2). Both are endothermic, as shown by the positive heat of reaction. The reaction requires heat transfer to maintain temperatures favorable to the equilibrium reactions.

$$CH_4 + H_2O(g) \xrightarrow{755-1,089K} 3H_2 + CO$$
$$\bullet \Delta H = 206 \text{ MJ}$$
(1)

$$CH_4 + 2H_2O(g) \xrightarrow{755-1,089K} 4H_2 + CO_2$$
$$\bullet \Delta H = 165 \text{ MJ}$$
(2)
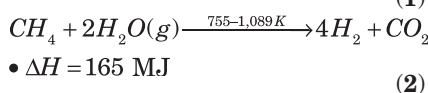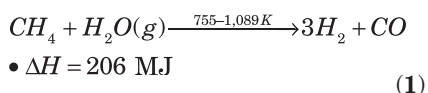
As the molecular weight of the feedstock increases, such as when heavier hydrocarbons (such as ethane, propane or butane) are included in the feed, the reactions are shown by Equations (3) and (4), with the corresponding heat requirements [2].

$$(CH_2)_n + nH_2O(g) \xrightarrow{755-1,089K} 2nH_2$$
$$+ nCO \quad \Delta H = 114 \text{ MJ}$$
(3)

$$(CH_2)_n + 2nH_2O(g) \xrightarrow{755-1,089K} 3nH_2$$
$$+ nCO_2 \quad \Delta H = 73 \text{ MJ}$$
(4)
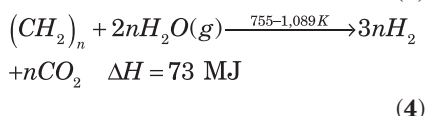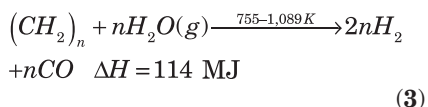
Product gas from the steam reforming of the methane and naphtha contains equilibrium amounts of hydrogen, carbon dioxide, carbon monoxide and

excess steam. The calculated effluent composition of a reformer always needs to be checked against the equilibrium constant equations to ensure that simulations agree with known values.

Excess steam above the theoretical requirements is maintained to prevent the reforming catalyst from coking. The temperature exiting the reformer furnace tubes is usually about 760°C (1,400°F), a level that provides maximum hydrogen production within the temperature limitation of the reformer tube metallurgy (discussed later).

Water-shift gas reactions
Additional hydrogen can be generated from the carbon monoxide byproduct following the reforming reaction. First, the reformer effluent gas is cooled in two steps to favor the equilibrium toward the right side of the reaction. The first cooling step is followed by the high-temperature shift reactor, and the second cooling step is followed by a low-temperature shift reactor. Shift reactions are promoted as effluent gas flows down through the fixed catalyst reactor containing a ferric oxide catalyst in accordance with the reaction in Equation (5). Note the water-shift reaction is exothermic, which results in a temperature increase across the reactors as water reacts with CO to form CO_2 and more H_2.

$$CO + H_2O(g) \xrightarrow{450-783K} H_2 + CO_2$$
$$\bullet \Delta H = -41 \text{ MJ}$$
(5)
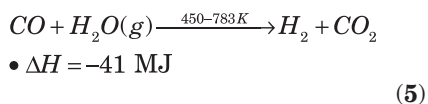
Water shift gas equilibrium is not affected by pressure, since there is no volume change. Reduced temperatures favor the conversion of CO to H_2, as might be expected by its exothermic nature. A variety of catalysts are available for the service.

HYDROGEN PLANT PROCESS
Figure 1 shows a schematic of a conventional steam-reforming hydrogen
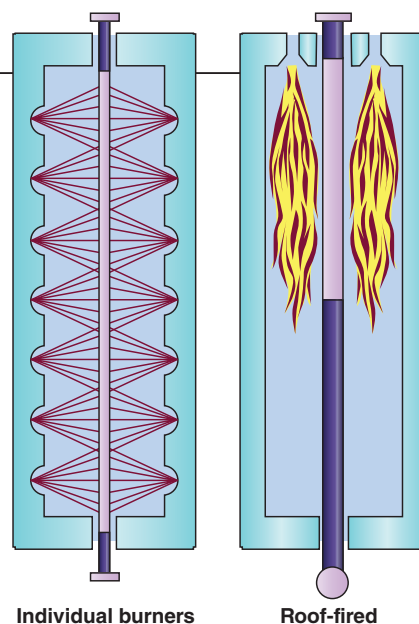
Individual burners   **Roof-fired**

FIGURE 2. Maintaining a tube-wall temperature that is hot enough for the reforming reaction is a critical factor in reformer heater design

plant [4]. The plant is based on a feed gas with high sulfur content, requiring plant operators to hydrotreat the feed before the zinc oxide removes the sulfur compounds. The H_2 purification at the end of the process is based on the removal of CO_2 with a pressure swing adsorber (PSA) system shown as the H_2 purification block. The reformer is shown as a vertical furnace type with side firing. The reformer furnace design alternatives will be discussed below.

Feed gas — usually a mixture of hydrogen, methane and other light hydrocarbons — is first compressed to about 300 psig. The initial compression has been found to provide product hydrogen at a pressure that can easily reach the desired hydroprocessing pressure with a four- or five-stage reciprocating compressor. This equipment is not part of the hydrogen plant.

The feed gas is preheated with reformer effluent gas and hydrotreated to convert the various sulfur compounds (such as mercaptans, carbonyl sulfide and carbon disulfide) to hydrogen sulfide. The gas is then passed through desulfurization reactors, usually containing a zinc oxide catalyst, which adsorbs the hydrogen sulfide. Low-sulfur feeds may not require the hydrotreating step.

Reforming furnace
The sulfur-free gas is mixed with a fixed amount of superheated steam to maintain the desired steam-to-hy-

drocarbon ratio. The steam-to-hydrocarbon ratio is kept within a range that is high enough to prevent laydown of coke on the reforming catalyst, but low enough to avoid overloading the reformer duty. Typically for a methane feed, the ratio would be three, whereas the theoretical requirement is somewhat less.

The combination of hydrogen and steam is heated to about 760°C (1,400°F). Since all of the reforming reactions are endothermic, additional heat is required to maintain the reaction temperature as the mixture flows down through catalyst-filled reformer tubes.

A critical factor in the reformer heater design is keeping the tube-wall temperature uniform and hot enough to promote the reforming reaction. Two types of heater designs have been employed for this purpose. Figures 2 and 3 show schematic diagrams of the side-firing reforming furnace, and the roof-fired heater design approach is shown in Figures 2 and 4.

Side-fired reforming heaters. The coil arrangement in a typical side-fired reformer furnace (Figure 3) consists of two parallel rectangular fire boxes connected at the top with horizontal duct work into the vertical convection stack. Two rows of vertical tubes arranged on a staggered pitch are present in each of the radiant boxes. Several (typically four) rows of burners are used to fire each side of the two radiant sections. This arrangement allows direct radiant fire to reach most of the tube wall. Platforms are provided to access the burners at each of the four burner levels. A typical reformer furnace could have over 300 burners. Reformer tubes typically have diameters of 5 in. (127 mm), walls 0.5-in. (13 mm) thick and about 34 ft (11.5 m) of wall exposed to the burners. The tube metallurgy is usually 25% chrome, 20% nickel or a high-nickel steel such as HL-40.
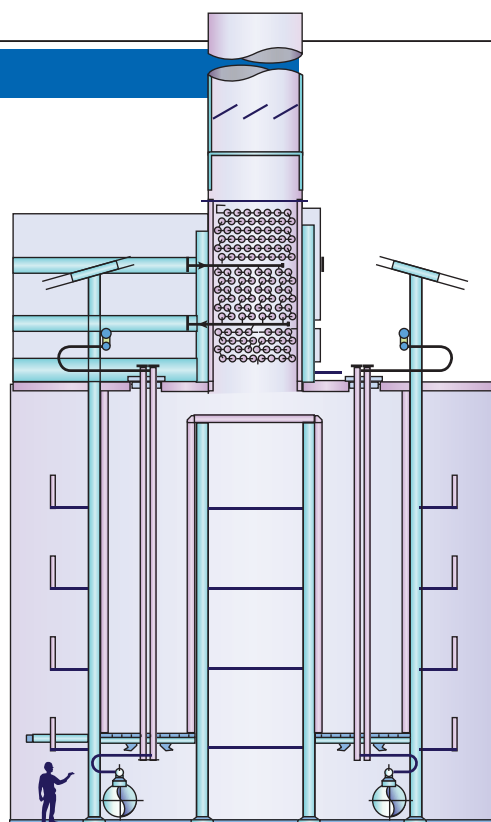
FIGURE 3. A typical reformer furnace could have over 300 burners

The inlet manifold at the top of the heater has "pigtails," which uniformly transfer the feed gas to the top of the tubes. Another manifold at the bottom of the heater connects another set of pigtails to the outlet transfer line. The pigtails provide for thermal expansion as the heater goes from startup temperature to reaction temperature. The objective is to have an equal pressure drop across each tube, which produces uniform flow to each of the tubes. The convection section includes several different coils. The hottest coil is a steam generation coil that protects the other coils from radiant heat. Usually, there is also a steam superheat coil, a feed preheat coil and another steam generation coil. Above these coils, there may be a boiler feed water (BFW) preheater and deaerator preheat coil.

Typically an induced draft fan is used to keep the fire box pressure slightly negative. Some reformers also have an air pre-heater and a forced draft fan.

Top-fired reformer. This type of reformer heater is usually a rectangular box. The tubes are still vertical, and inlet and outlet pigtails are used to connect the inlet header and the outlet transfer line, respectively. Figure 4 shows a schematic diagram
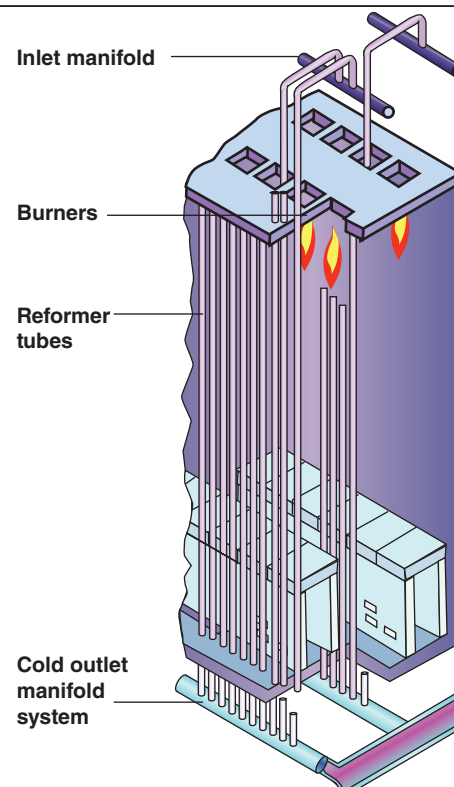
FIGURE 4. Hydrogen plants with single heaters and capacities up to 100,000 ft³/d have used a down-firing approach

of a down-fired reformer furnace [9].

The tubes are spaced on a pitch, which allows the burners to fire down between the tubes. The burners have a special "pencil-shaped flame" design. All burners are located in the penthouse above the inlet manifold. The flame and the flow through the tubes travel in the same direction.

Hydrogen plants with single reformer heaters and capacities up to 100 million ft³/d have used the vertical, down-firing approach. Each burner's radiant flame covers one-quarter of four adjacent vertical tubes (except for the outside burners, which cover half of the two adjacent tubes).

The radiant gases exit the box horizontally through a horizontal convection section. The horizontal convection section is located about 3 m above grade to allow enough height for passage. The horizontal convection provides for a simpler support structure than that of the side-fired unit.

Transfer-line steam generator

The outlet transfer line from the reformer is used to generate high-pressure (usually 650 psig) steam. The reformer effluent gas exits through the transfer line at about 1,400°F and enters the tube side of a single-pass
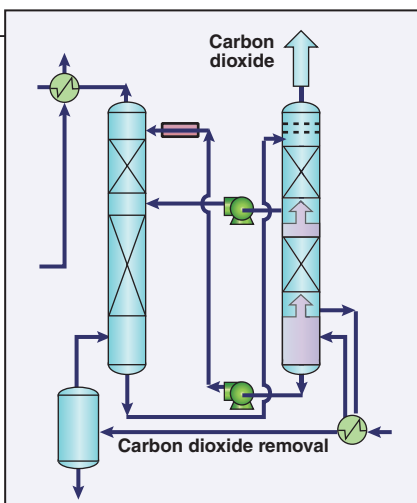
FIGURE 5. Most older units remove carbon dioxide from the hydrogen-rich gas with a solvent

FIGURE 6. A PSA unit separates carbon monoxide, carbon dioxide and unconverted hydrocarbons from hydrogen. Adsorbers operate in a high-pressure to low-pressure cycle to adsorb and then release contaminants

steam generator. BFW is fed through the shell side and becomes 650 psig steam. Depending on the size of the reformer, there may be two transfer lines exiting opposite ends of the reformer and feeding two steam generators. Figure 3 shows the two transfer line steam generators.

Feed preheat exchanger. Gas is cooled to about 650°F and is moved out of the steam generator. It then enters the tube side of the feed preheat exchanger. Feed gas is preheated to about 600°F using heat from the effluent gas. This temperature can be controlled by partial bypass of the effluent side to maintain the desired hot-shift gas reactor temperature.

Hot shift-gas reactor. Effluent gas containing carbon monoxide and steam is passed over the hot gas-shift catalyst, where the water-shift gas reaction shown in Equation (5) occurs. This reaction is slightly exothermic, resulting in a temperature rise across the reactor.

More steam generation. Additional medium-pressure steam is generated, reducing the hot-shift reactor effluent to a temperature of about 500°F, which shifts the reaction equilibrium toward more hydrogen production.

Cold shift-gas reaction. Additional hydrogen is produced by the gas-shift reaction at the lower temperature. The shift reaction is exothermic, which results in a temperature rise across the reactor.

Condensate removal. Cold gas-shift effluent is cooled by heat exchange with BFW, deaerator feedwater, and cooling water to about 34°C (100°F). Condensate is separated from the gas in a vertical knockout drum.

Hydrogen purification

Hydrogen purification is generally carried out using one of two approaches — solvent-based systems or pressure-swing adsorption (PSA) processes.

Solvent systems Most older units remove carbon dioxide from the hydrogen rich gas using a solvent, such as Catacarb or amines, in a typical acid gas separation unit (Figure 5).

Remaining carbon oxides (primarily carbon monoxide) are reacted with hydrogen in a methanator reactor to convert them to methane. Methane is an undesirable component in the makeup gas to a hydrocracker because it builds up in the recycle gas, requiring bleeding of the recycle gas to maintain the desired hydrogen partial pressure in the hydrocracker.

Most solution-type carbon dioxide removal systems are similar. Gas enters the bottom of the absorber, where it contacts lean solution. The carbon dioxide is absorbed from the gas, leaving the rest of the contaminants and hydrogen relatively untouched.

The rich solution is then heat-exchanged with lean solution and enters the top of the stripper. The stripper uses a steam reboiler to regenerate the solvent, stripping out the absorbed carbon dioxide. The overhead from the stripper goes through a condenser to condense solvent and then to an overhead drum, where the carbon dioxide is separated from the stripper reflux.

PSA unit. The newer PSA process produces a hydrogen stream of four-nines (99.99%) purity. It separates carbon monoxide, carbon dioxide and unconverted hydrocarbons. A bank of adsorbers operates in a cycle where the adsorbers are rotated through a

higher-pressure adsorption portion, followed by a pressure reduction, which allows the contaminants to be released from the adsorber. The hydrogen gas passes through the adsorber as almost-pure hydrogen. The contaminants flow into a fuelgas surge drum.

Figure 6 shows a schematic diagram of such a system. The valve openings and closings are all controlled by the central processing unit.

The fuel gas is relatively low-BTU carbon oxides. It is supplemented with natural gas or other fuels as feed to the reformer furnace burners.

Pre- and post-reforming

These are two techniques used to expand the capacity of exisiting plants where the reformer furnace is heat-transfer-limiting.

Pre-reforming Pre-reforming is used when spiking the feed with liquified petroleum gas, which is used to increase the capacity of the existing unit. Examining the reforming Equations (1), (2) and (4) reveals the advantage of a heavier feed that yields more hydrogen per feed mole. The pre-reformer reaction breaks down the heavier hydrocarbons (propane and butane) to methane ahead of the heat-intensive reforming reactions, essentially shifting part of the load upstream of the reformer heater as shown in Figure 7 [8].

Feed at 950°F passes down through the pre-reformer reactor, where the breakdown reactions occur. Then the pre-reformed feed passes through another convection coil to reheat it to about 1,100°F before entering the reformer.

Adding the pre-reformer as a retrofit to an existing facility presents two problems — one of space and one
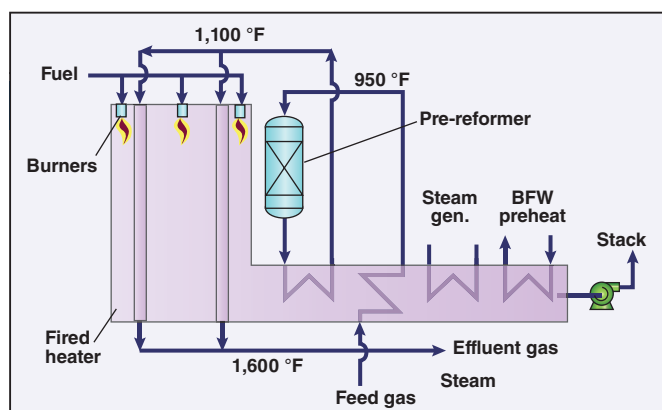
FIGURE 7. A pre-reformer breaks down heavier hydrocarbons into methane ahead of the reforming reactions

of compatibility. Physical space constraints may not allow adding a feed reheat coil within the convection section. Also, the metallurgy of the inlet pigtails may not be able to handle the higher feed temperature.

Post-reforming. Post-reforming is an attempt to provide additional reforming catalyst outside the reformer heater. A down-flow reactor is added between the outlet transfer line and the waste heat steam generator. This can present a space and piping problem. The additional post-reformer catalyst reduces the overall total space velocity of the combined reformer and post reformer, thus achieving additional reaction. This reduces the downstream shift-reaction requirements. ■

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Author

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

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Wireless Communication in Hazardous Areas

Stephan Schultz
R. Stahl

Consider these criteria in deciding where wireless fits in today's CPI plants and the explosive atmospheres that permeate them

Wireless communications have great potential in the chemical process industries (CPI) because they do away with complex and costly cable installations and enable completely new applications. And while a recent wave of successful demonstrations has begun to emerge in the CPI (for more, see *CE*, Nov. 2009, p. 17–23), a number of hurdles stand in the way of a completely wireless Utopia. In most cases, the totally reliable, uncompromised availability of a production plant remains a paramount objective, and it will therefore likely take some more time before radio transmissions of critical signals in control loops take root.

One impediment often cited as a limit for wireless solutions is power. In fact, many process applications basically rule out wireless field devices without an independent, onboard source of power. Granted, there have been a number of promising approaches in this regard, which are based on consumption-optimized electronic circuits and alternative sources of power using accumulators or solar cells, or on so-called energy harvesting, where energy is recovered from vibration, temperature fluctuations, and so on.

At the same time, there are a range of ancillary functions in almost any plant today for which wireless communications truly are already a boon. In these cases, power is not an insurmountable hurdle because the power requirements are low enough to maintain battery life of five or more years. Meanwhile, the use of wired power should not be ruled out automatically.

In existing plants, power sources are around nearly every corner, so the cost of wiring for power is not nearly as significant as the cost of the wiring for the control signals themselves.

A look at typical routines in process plants will identify the potential ancillary application areas with a view to how and how much they may benefit. Once a case is made for wireless technology in general for these purposes, users are faced with various solutions to choose from for actual implementations. And last but not least, there are additional safety considerations for applications in hazardous areas. All of these aspects will be discussed in order to enable users to make informed choices, or to at least prime themselves for further consultations with specialist manufacturers or systems solution providers.

APPLICATION AREAS

Logistics and supply chain

State-of-the-art logistics solutions depend on systems that acquire data on the flows of goods with the highest possible degree of precision, and preferably at the very instant when stock items are taken out or replenished. In the CPI, many raw materials and products are transported in containers such as drums, tanks, intermediated bulk containers (IBCs), and so on. Most containers are marked with either barcodes or RFID (radio-frequency identification) tags. Acquiring RFID tag information is an obvious model application for wireless technology. As of yet, though, most reading devices used for this purpose are handheld terminals with a cable that curtails their operation. Portable radio devices capable of both acquiring data and passing it on via wireless link to MES (manufacturing execution system) and ERP (enterprise resource planning) servers save time and costs, and increase data reliability due to exact and nearly instant data acquisition. RFID tags can be expected to increase their foothold in the CPI due to reliability and safety benefits, since one key RFID advantage over barcodes is that even smudged and stained labels are still legible. Also, there are other convenient features that previous solutions could not provide; for instance, data can be written to the tags more than once and it is possible to acquire several tags at the same time.

Maintenance and monitoring

Anyone in the field who is servicing a plant is likely to benefit from using portable devices with a connection to a central management system, since doing so enables optimization of typical routines and measurements. For example, maintenance instructions can be automatically dispatched because all relevant information can be provided via radio to a portable handheld device that service engineers can carry with them in the field. Staff are then able to inspect equipment as

needed and, upon completion or even while they are taking care of a maintenance task, enter the results of the inspection, or repairs made, directly into the portable device. Those data are then instantly available in a central database and can be utilized, for instance, for documentation purposes or even to speed up billing. Similar advantages apply to operating and monitoring tasks in industrial plants. Portable devices make it possible to read realtime measured values and therefore keep an eye on the actual state of the production plant onsite. At the same time, operators in the field have access to ancillary information such as maintenance schedules, operating instructions, ATEX or other hazardous area certificates and much more. As a result, routine procedures can be modified to become considerably more efficient.

Security and asset management

Using radio transmission, camera systems or sensors at distant measuring points — for instance, within pump stations — can be integrated into the site's human-machine-interface (HMI) concept at a low cost and can be readily displayed where needed. While process signals in the narrow sense are absolutely needed to ensure proper control of a plant, a host of other measured values may be useful only for operative improvements or preventive maintenance. Radio transmission is a good alternative for such signals not only if they are particularly hard to acquire any other way, but, more broadly, for all kinds of non-critical asset management data.

For the time being, HART communication is most commonly implemented to transmit signals that are only used for process optimization and similar purposes. Wireless solutions are well suited to satisfy the growing demand for higher-level asset management. There is good cause for its increasing importance in the process industry: live information about the current state of production equipment in a plant in as much detail as possible gives staff a better means to anticipate imminent plant failures and to adjust maintenance intervals to actual needs.

NETWORKING OPTIONS

Whatever functions are to be enabled, all wireless network installations require thorough planning, which starts with the definition of the requirements for the wireless network. A range of aspects has to be considered, including bandwidth, mobility, hardware requirements in terms of realtime signal transmission, the encryption system, information-technology (IT) department demands and so on.

1. Using a floor plan, it is possible, in principle, to assess the radio frequency (RF) coverage in the area with the aid of planning programs. However, practical experience shows that the effort to emulate the complete structure of a CPI plant is too high. Experience is the key to success. Meanwhile, users deploying a new network also have to know exactly which wireless systems are already in use in the same place and in neighboring areas. The location and selection of the antennas can then be established.

2. In the next step, the deployment plan should be verified against a so-called onsite survey. This is a live onsite inspection of the area to check the values previously determined on the computer in the real environment, using a portable access point. In this confirmation process, some additional information can be gathered that cannot be anticipated in a floor plan, such as the effects of vehicles passing through, or of mobile containers that may have appeared in the way in unexpected places. The survey will also allow users to realistically determine the effective bandwidth in the central and the outer areas of RF coverage.

3. Finally, the RF system can be installed, commissioned, and put through a final test under real operating conditions to avoid unpleasant surprises.

While the many steps of this procedure might appear to drive expenses up, they have indeed proven to be by far the most reliable way to ensure that a new wireless system really works as expected and brings about the desired process improvements. Obviously, wireless communications can be implemented using a variety of different radio technologies. As is so often the case, there is no one standard that meets all requirements.

FIGURE 1. State-of-the-art Wireless LAN systems ensure secure data handling, unlike earlier versions, which were easier to crack

Most users will therefore have to examine at least some of the following options to assess whether they fit the application at hand.

Wireless LAN

All radio technologies currently available on the market have specific advantages and disadvantages. It is worth noting, however, that the most widely used solutions have originated in the office IT sector and were not genuine developments for industrial applications. Wireless LAN (local area network) is the most prominent case in point. In an industrial environment, Wireless LAN (WLAN) is quite suitable for use with portable equipment, such as barcode scanners or handheld HMI devices. It provides the greatest bandwidth (for IEEE 802.11b, 11 Mbit/s, or IEEE 802.11g, 54 Mbit/s gross data throughput) and is designed for the transmission of Ethernet-based protocols. It is important to keep in mind, though, that most CPI applications only require bandwidth in the 100–500 kbit/s range.

In a WLAN network, an access client, such as a PDA (personal digital assistant), can also roam from one access point to another without any interruption in transmission. This means users carrying portable devices can move freely around the site without losing their connections to the network. State-of-the-art WLAN systems also ensure secure data handling, unlike earlier versions, which only relied on Wired Equipment Privacy (WEP),

FIGURE 2. This WirelessHART gateway is suitable for Zone 2 areas

WLAN's original, out-dated encryption method that was very easy to break by brute force.

GPRS on public GSM networks

The General Packet Radio Service (GPRS) enables the transfer of data packets on the public radio networks that were originally built for cellphone voice communications, and have since been enhanced for other data transfer. GPRS is, for instance, the base for the popular Blackberry technology. In CPI applications, the service can be used for remote maintenance and remote monitoring functions in pumping stations, remote tank farms, centrifuges, compressors and other machines. Unlike WLAN, GPRS operates on a licensed frequency range, which means that less interference occurs in the radio connection than in the frequency bands used by most other established wireless-data-communications standards. Since it is based on the existing, fully developed Global System for Mobile Communications (GSM) mobile networks, GPRS requires no extra investments for a purpose-built, self-run radio system. On the contrary, GPRS connections constitute communication routes that are totally independent from a company's own, existing IT infrastructure. Also, the technology can be used for additional services, such as alerting responsible staff via text message or Email in case of a malfunction.

Some restrictions and weak points must be taken into account, however. GPRS is, for instance, not yet universally available worldwide. In some countries, such as Japan and Korea, GPRS coverage will remain unavailable, since these countries' mobile radio networks do not use the GSM standard. A more extensive coverage and better bandwidth will only be achieved when the followup technology to GPRS, the so-called UMTS service, becomes well established around the world. Last but not least, with a net bandwidth of only 50 kbit/s, GPRS is also considerably slower than WLAN and other radio protocols.

Bluetooth

Bluetooth does not provide a bandwidth that can match WLAN network performance, but recent systems do achieve transmission rates of up to 2 Mbit/s. In addition, due to its synchronous communication modes, Bluetooth provides a very good basis for realtime applications. One key Bluetooth feature is the frequency hopping spread spectrum (FHSS) scheme, which makes this technology significantly less susceptible to interference than WLAN. FHSS also provides some additional protection against eavesdroppers. Bluetooth works well for networks with up to eight users, while greater numbers will require increased technical efforts. Bluetooth radio consumes less power in operation than WLAN. Due to its characteristics, it is particularly suitable for integrating fixed devices such as HMI stations or sensors. Like WLAN, Bluetooth boasts specifications that have been internationally agreed upon, which ensures that devices from different manufacturers are fully, or at least to a great extent, compatible with each other.

WirelessHART and ISA 100.11a

WirelessHART and ISA 100.11a are standards that are dedicated for sensor networks in the CPI. Both standards promise to connect field devices of various vendors onto one network. The network structure could be point-to-point, star or — the most interesting way — meshed. The meshed structure offers two advantages. First of all, if a field device is installed out of the range for a direct connection to the gateway, it may use a neighboring field device as a repeater. This method extends the communication range. Secondly, the meshed structure enables a self-healing of the network in case of interruptions, which could happen, for instance due to delivery or service trucks parking in front of a device. The first field trials have proven that the technology and components are ripe for industrial use.

Both WirelessHART and ISA 100.11a committees are working together to find a way to merge both standards or enable interoperability. This would be important to tearing down the last obstacle for the success of wireless technology in the CPI.

Coexistence

While the industrial-scientific-medical (ISM) frequencies (the radio bands at 2.4 GHz used by most common wireless solutions) are licence-free and therefore help to reduce operating costs, they do have the disadvantage that they must be shared by different applications. The standardization forums are aware of this fact and have come forth with some adequate approaches for resolving potentially problematic side effects. For instance, Bluetooth's adaptive frequency hopping scheme enables an operation of WLAN and Bluetooth networks at the same time in the same environment. WirelessHART and ISA 100 enable a so-called blacklisting of channels, which are occupied by other wireless applications. Given thorough and sensible wireless network planning and deployment, interference can be practically eliminated in most scenarios. Besides the more or less established standards just discussed, there are numerous other proprietary protocols. However, users will more often than not be inconvenienced by them due to incompatibilities between devices from different vendors. Based on the existing standards for WLAN, Bluetooth WirelessHART and ISA 100 technology, various committees and organizations in several countries have been trying and keep trying to improve standardization and provide users and manufacturers with implementation guidelines. Major protagonists include the German VDI/VDE GMA working committee 5.21, the ZVEI, and a Namur subcommittee. Contributions in this field also come from organizations such as the ISA's (Instrumentation, Systems and Automation Society of America) SP100 committee and the HCF's (HART Communication Foundation) WirelessHART.

HAZARDOUS AREAS

Radio devices emit electromagnetic radiation that is clearly a possible source of ignition in an explosive atmosphere.

The main risk lies in the induction of electrical currents in metallic objects or electronic circuits that are inadequately protected from electromagnetic interference (EMI). These currents can result in excessively high temperatures and the formation of sparks. Other dangers, such as direct ignition of an explosive atmosphere, are much less relevant. IEEE studies on electromagnetic radiation in hazardous areas have shown that even RF with power of 6 W can become a potential hazard in terms of induction in metal objects. Because of this danger, the IEC 60079-0 2008 and the upcoming EN 60079-0 for continuous high frequency sources limit the maximum permitted

FIGURE 3. An external antenna in wireless units, such as this access point, is currently required to attain an individual ATEX certification for use in hazardous areas

transmitting power in wireless networks that are operated in hazardous areas. The location of a wireless node in Zone 0, 1 or 2 can be disregarded and has no relevance for the limit, since an RF signal will obviously not stop at the boundary between two zones.

Safe emission levels

The threshold is set to a value between 6 and 2 W emitted power, with the lower end applying to atmospheres with group IIC explosive gases, such as hydrogen or acetylene. WLAN, Bluetooth, WirelessHART and ISA 100 all predominantly use the aforementioned ISM bands at 2.4 GHz, which are restricted to low-power radio transmissions anyway. More specifically, WLAN access points using this band are limited by RF regulations to no more than 100 mW. Fortunately, Bluetooth, WirelessHART and ISA 100 transmissions typically require only about 10 mW of energy in the first place. At face value, all of these technologies therefore need or can do with significantly less energy than the maximum allowed by the standard.

However, the so-called antenna gain must also be factored into the calculation, as the ignition risk is also defined by the magnitude of the field strength. Antenna gain is a parameter that describes the concentration of radio energy emitted in a specific direction. Such directional gain increases as radio emissions in other directions decrease because the total energy emitted remains the same. Antenna gain is measured in relation to a specific reference. If the gain value is stated in dBi units, then it refers to an isotropic radiator, or omnidirectional radiator (the theoretical model of an antenna that evenly distributes energy in all directions from a point source). Typical values for rod antennas and directional antennas

are between 5 and 9 dBi. Users have to take antenna gain into account when they refer to the values given in the tables in IEC 60079-0.

Suitable Zone 1 device designs

With few exceptions, automation components and devices currently available on the market must not be used in Zone 1* right out of the box. This restriction is largely a consequence of the rapid pace of development for new devices, which are released in very short intervals and are therefore often affected by incomplete standardization.

One possible solution to the problem is an installation of such RF equipment without Zone 1 approval in housings featuring a flameproof enclosure. This includes Ex d type of protection, or another suitable type. The majority of all Ex d enclosures are made of metal, which shields electromagnetic radiation from the antenna as a side effect. Obviously, not just any antenna can be installed inside a housing of this type without additional measures. In some cases, a housing with a glass pane can be used in combination with a directional antenna installed within. However, tests have shown that only antennas specially matched to a particular type of flameproof enclosure will actually work well, since the signal loss is otherwise excessive.

Another possible option is the use of external antennas. However, hazardous area requirements demand that special explosion-protected antennas have to be installed in this case. They usually have to be designed for increased safety (Ex e) protection, because, in the event of a short circuit between the power supply and the output or input stage in the RF device, no excessively high currents or voltages are allowed to coincide with the explosive atmosphere without protection. Zone 1 GPRS modems typically have GSM antennas connected via an Ex i interface, and also feature an intrinsically safe Ex i SIM card slot. One way to do away with most limitations concerning the choice of antenna would be antenna breakouts for devices in encapsulated housings that

implement Ex ib (intrinsically safe) type protection, which would allow for communication via an intrinsically safe HF signal. Such solutions are currently in development. Once they actually become available, users will finally have access to the full range of standard antennas. ■

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Author

Stephan Schultz is senior product manager automation, isolator and wireless at R. Stahl (Am Bahnhof 30, 74638 Waldenburg, Germany; Phone: +49 7942-943-4300; Fax: +49 7942-943-404300; Email: stephan.schultz@stahl.de; Website: www.stahl.de).

* For a one-page reference card on hazardous area classifications, see http://www.che.com/download/facts/CHE_0507_Facts.pdf

Engineering Practice

SPIRAL PLATE HEAT EXCHANGERS:
Sizing Units for Cooling Non-Newtonian Slurries

This article presents step-by-step guidance to demystify the sizing of these exchangers

Angelo A. Moretta*
Bechtel National

Spiral plate heat exchangers are ideal for cooling slurries and viscous fluids. The performance of these units is characterized by increased turbulent heat transfer, reduced fouling, greater ease of maintenance, and more compact size compared to many competing options.

In a spiral plate heat exchanger, the hot fluid enters at the center of the unit and flows from the inside outward (Figure 1). The cold fluid enters at the periphery and flows toward the center. Heat transfer is carried out by the countercurrent flow that is achieved. Both fluid streams flow in identical passage configurations, and therefore have the same heat transfer and pressure drop characteristics.

Heat transfer analysis

The amount of heat exchanged between the hot and cold fluids inside a spiral plate heat exchanger can be found by performing a simple energy balance around the appropriate section of the exchanger using this general relationship:

Energy lost by the hot fluid = Energy gained by the cold fluid + Energy lost to the surroundings

The energy lost to the surroundings is assumed to be negligible.

The actual heat balance in a spiral plate heat exchanger is calculated by

* Moretta is a mechanical engineer with Bechtel National (Richland, Wash.). He received his training at the Massachusetts Institute of Technology (MIT; Cambridge) and the University of California at Berkeley.

applying the first law of thermodynamics (see p. 48 for Nomenclature):

$$Q = m_h c_h (T_{hi} - T_{ho}) = m_c c_c (T_{co} - T_{ci}) \quad (1)$$

The overall heat transfer coefficient, U, provides a common way to express the heat transfer rate for a given system. A detailed derivation of the overall heat transfer coefficient can be found in any heat transfer textbook. The result can be written as:

$$Q = U A f \Delta T_{LM} = U A f (LMTD) \quad (2)$$

The overall heat transfer coefficient, U, is:

$$U = \frac{1}{\dfrac{1}{h_h} + \dfrac{t}{k_P} + \dfrac{1}{h_c} + R_f} \quad (3)$$

[Ref. 2, p. 60]

The logarithmic mean temperature difference (LMTD) between the inlet and outlet streams is determined using Equation (4).

$$LMTD = \frac{(T_{hi} - T_{co}) - (T_{ho} - T_{ci})}{\ln \dfrac{(T_{hi} - T_{co})}{(T_{ho} - T_{ci})}} \quad (4)$$

The heat transfer surface area, A, represents both sides of the plate that is used to form the spirals inside the heat exchanger:

$$A = 2LH \quad (5)$$

The maximum plate width that fabricators of today's spiral-plate heat exchangers have available is 72 in. The length of this plate is adjusted to provide an optimum heat transfer surface and acceptable pressure drop.

The values of these parameters are assumed at first in this iterative process, and then checked to ensure that the proposed values will provide a good heat transfer surface and an allowable pressure drop.

Combining Equations (2), (4) and (5) (and setting $f = 1$; f is a correction factor for countercurrent flow in a spiral plate heat exchanger) gives the following relationship:

$$Q = U A (LMTD)$$
$$= U(2LH) \frac{(T_{hi} - T_{co}) - (T_{ho} - T_{ci})}{\ln \dfrac{(T_{hi} - T_{co})}{(T_{ho} - T_{ci})}} \quad (6)$$

Calculate the hot-side and cold-side film heat transfer coefficients. One of the most recent correlations to determine the film heat transfer coefficient in a spiral plate heat exchanger handling well slurries and water is the Morimoto and Hotta correlation [Ref. 3, Equation (38), p. 62]:

$$Nu = 0.0239 \left(1 + 5.54 \frac{D_H}{R_M} \right) Re^{0.806} Pr^{0.268} \quad (7)$$

Equations (7) and (17) will be used twice to determine the heat transfer coefficients defined in Equation (3) for the hot side and cold side. The equations that follow [Equations (8) through (18)] are written generically — that is, the fluid specific parameters will not be written as h_h or h_c but rather as just h.
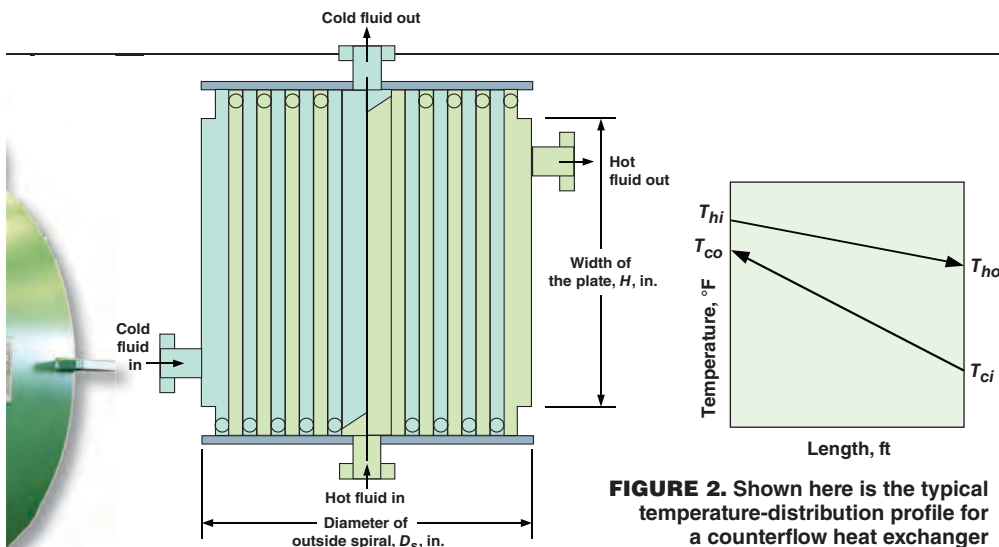
FIGURE 1. As shown in this cross-section of spiral plate heat exchanger, countercurrent flow achieved inside the unit enables efficient heat transfer

FIGURE 2. Shown here is the typical temperature-distribution profile for a counterflow heat exchanger

The Reynolds number, Re, is defined as follows [Ref. 4, p. 16]:

$$Re = \frac{GD_H}{\mu} \qquad (8)$$

The mass flux, G, is defined by Equation (9) [Ref. 4, p. 16]:

$$G = \frac{m}{A_C} = \frac{m}{HS} \qquad (9)$$

The average hydraulic diameter, D_H, is defined as:

$$D_H = \frac{2HS}{H+S} \cong 2S \qquad (10)$$

Thus, the hydraulic diameter is approximately twice the spacing. This is justified because in most spiral-plate heat exchangers, the width of the passage, H, is considerably larger than its spacing [Ref. 4, p. 16]. If needed, the spacing can be increased to provide a pressure drop lower than the maximum allowable.

The apparent viscosity, μ, is determined as follows:

$$\mu = \frac{\tau}{\gamma} \; 1{,}000 \qquad (11)$$

$$\tau = \tau_o + \frac{\eta \gamma}{1{,}000} \qquad (12)$$

The strain rate, γ, is determined from the relationship provided in [Ref. 7, p. 6-13]. In the application of sizing spiral plate heat exchangers for cooling non-Newtonian slurries, the diameter, D, of the pipe must be replaced by the average hydraulic diameter of the channel D_H. Thus:

$$\gamma = \frac{8V}{D_H} \qquad (13)$$

The velocity is calculated by dividing the mass flux by the density:

$$V = \frac{G}{\rho} \qquad (14)$$

The spiral mean radius, R_M, is defined by Equation (15) [Ref. 3, p. 63]:

$$R_M = \frac{R_{\max} + R_{\min}}{2} \qquad (15)$$

The Prandtl number, Pr, is defined as:

$$Pr = \frac{\mu c_P}{k} \qquad (16)$$

As shown above, the Nusselt number, Nu, can be calculated from Equation (7). It can also be calculated from Equation (17) [Ref. 7, pp. 3–90, Table 3-8]:

$$Nu = \frac{hD_H}{k} \qquad (17)$$

Solving for h gives:

$$h = \frac{kNu}{D_H} \qquad (18)$$

By substituting the value for Nu from Equation (7), the heat transfer coefficient can be calculated. After the heat transfer coefficients are obtained, U can be calculated from Equation (3). Using the value of U, the total heat transfer, Q, can be calculated from Equation (6). This value is defined as the "actual duty."

The percentage over-surface design, OS, which is typically added to provide a margin of safety, is determined from Equation (19):

$$OS = 100 \left(\frac{Actual\ duty}{Operating\ duty} - 1 \right) \qquad (19)$$

The value of OS is increased by assuming a larger value for L in Equation (6).

Analyze pressure drop. The pressure drop in a spiral plate heat exchanger with studs is presented in [Ref. 7, Equation (11–81), p. 11-55]:

$$\Delta P = \frac{1.45(LV^2 \rho)}{1.705 \times 10^3} \qquad (20)$$

To convert the pressure drop from kPa to psi, multiply the result in kPa by 1.45. The constant 1.45 is used for 60-x-60-mm studs (such dimensions are typical, as noted in [Ref. 7]).

Determine the outside spiral diameter. The diameter of the outside spiral is determined using the empirical Equation (21), as presented in [Ref. 6, p. 112]:

$$D_S = \left[\; 15.36\, L(S_h + S_c + 2t) + C^2 \; \right]^{\frac{1}{2}} \qquad (21)$$

Sample calculation

The assumptions described below are referenced in the next sections.

1.1 The physical properties of the hot slurry through the heat exchanger are assumed as:
   - Specific gravity S_g = 1.35
   - Yield stress τ_0 = 30 Pa
   - Consistency viscosity η = 30 cP
   - Specific heat c_p = 0.9 Btu/lb$_m$ °F
   - Thermal conductivity k = 0.36 Btu/h ft°F

   The assumed dimensions of the proposed spiral plate heat exchanger are:
   - Plate width = 36 in.
   - Plate thickness = 0.125 in.
   - Core diameter = 12 in.
   - Minimum radius of spiral = 6 in.
   - Maximum radius of spiral = 10.75 in.
   - Channel spacing, hot side = 1.25 in.
   - Channel spacing, cold side = 0.25 in.

1.2 The operating heat duty is assumed to be 750,000 Btu/h.

1.3 The operating volume flowrate for the hot side is 1,500 gal/min.

1.4 The operating volume flowrate for the cold side is 300 gal/min.

1.5 The outlet temperature of the slurry in the vessel is 77°F.

1.6 The maximum allowable pressure drop is 25 psi.

1.7 The heat losses to the surroundings are negligible. This assumption is based on engineering judgment and consultation of [Ref. 1, pp. 17–27].

1.8 The inlet temperature of the cooling water is 50°F.

1.9 Cooling water specific gravity, S_g = 0.9992 ≅ 1.0.

1.10 The physical properties of water at 50°F and 60°F are those specified in [Ref. 5, Appendix 35.A, p. A-93]. The physical properties of water at 55°F were obtained by interpolation:
- Viscosity μ = 0.00082 lb_m/ft s = 1.219 cP
- Specific heat c_c = 1.0 Btu/lb_m °F
- Thermal conductivity k = 0.336 Btu/h ft °F = 9.33(10)$^{-5}$ Btu/s ft°F
- Density ρ = 62.35 lb_m/ft^3

1.11 For countercurrent flow through a spiral heat exchanger, the correction factor is equal to 1 [Ref. 2, p. 60].

1.12 The fouling factor, R_f, for spiral heat exchangers varies between 0.0003 and 0.001 h°Fft^2/Btu [Ref. 2, Table 1, p. 62]. In this calculation, a mid-value between the two extremes is used. Thus, R_f = 0.0006 h°Fft^2/Btu

1.13 To decrease the investment cost and still satisfy the process specifications, an over-surface design between 20 and 30% is specified.

1.14 Thermal conductivity of 316 stainless steel is 14.538 W/mK at 293.15K [Ref. 1, pp. 2–59]. The corresponding value in the English system is 8.4 Btu/h ft°F at 68°F

Determine the slurry inlet temperature.

Q = 750,000 Btu/h (an operational requirement, Assumption 1.2)

c_h = 0.9 Btu/lb_m°F (Assumption 1.1)

S_g = 1.35 (Assumption 1.1)

T_{ho} = 77°F (Assumption 1.5)

1 gal (water) = 8.34 lb_m (Standard conversion factor)

1 h = 60 min (Standard conversion factor)

Then for the operating volume flowrate of 1,500 gal/min (Assumption 1.3), the mass flowrate, m_h, is:

$$m_h = (1{,}500\,\frac{gal}{min})(8.34\,\frac{lb_m}{gal})\bullet$$

$$(\frac{60\,min}{h})(1.35) = 1{,}013{,}310\ lb_m\,/\,hr$$

Using Equation 1:

$$Q = m_h\,c_h(T_{hi} - T_{ho}) \Rightarrow$$

$$T_{hi} = \frac{Q}{m_h\,c_h} + T_{ho}$$

$$= \frac{750{,}000\,Btu\,/\,h}{(1{,}013{,}310\,lb_m\,/\,h)(0.9\,Btu\,/\,lb_m{}^oF)}$$

$$+ 77\,{}^oF \cong 77.82\,{}^oF$$

T_{hi}=77.82°F

Determine the chilled water outlet temperature. From Equation (1):

$$Q = m_h\,c_h(T_{hi} - T_{ho}) = m_c\,c_c\,(T_{co} - T_{ci})$$

where:

m_h = 1,013,310 lb_m/h (from the section above: Determine the slurry inlet temperature)

$$m_c = (300\,\frac{gal}{min})(8.34\,\frac{lb_m}{gal})\bullet$$

$$(\frac{60\,min}{h})(1.0) = 150{,}120\ lb_m\,/h$$

(Assumption 1.4)

c_c = 1.0 Btu/lb_m°F (Assumption 1.10)

T_{hi} = 77.82°F (from the section above: Determine the slurry inlet temperature)

T_{ho} = 77°F (Assumption 1.5)

T_{ci} = 50°F (Assumption 1.8)

Substituting in Equation (1), we have:

$m_h\,c_h\,(T_{hi} - T_{ho}) = m_c\,c_c\,(T_{co} - T_{ci})$

(1,013,310 lb_m/h)(0.9 Btu/lb_m°F) (77.82 °F − 77 °F) = (150,120 lb_m/h) (1.0 Btu/lb_m°F)(T_{co} − 50°F)

147,822.78 Btu/h) = 150,120 Btu/h°F (T_{co} − 50°F)

4.982°F = (T_{co} − 50°F)

T_{co} = 50°F + 4.982°F = 54.982°F ≅ 55°F

Calculate the LMTD. From Equation (4):

$$LMTD = \frac{(T_{hi} - T_{co}) - (T_{ho} - T_{ci})}{\ln\dfrac{(T_{hi} - T_{co})}{(T_{ho} - T_{ci})}}$$

$$= \frac{(77.82 - 55) - (77 - 50)}{\ln\dfrac{(77.82 - 55)}{(77 - 50)}} = \frac{22.82 - 27}{\ln\dfrac{22.82}{27}}$$

$$= \frac{-4.18}{\ln(0.8452)} = 24.85\,{}^oF$$

Calculate the film heat transfer coefficient for the hot side. The film heat transfer coefficient for the hot side is determined as follows:

From Equation (10):

$(D_H)_h \cong 2S_h$ = 2(1.25 in.) = 2.5 in. ≅ 0.210 ft ([Ref. 4, p. 16] and Assumption 1.1)

From Equation (15):

$$R_M = \frac{R_{max} + R_{min}}{2} = \frac{10.75\,in. + 6\,in.}{2}$$

$$= 8.375\,in. = 0.698\,ft$$

([Ref. 3, p. 63] and Assumption 1.1)

To determine the Reynolds number, the mass flux is determined first from Equation (9):

$$G_h = \frac{m_h}{A_C} = \frac{m_h}{H\,S_h}$$

$A_c = HS_h$ = (36 in.)(1.25 in.) = 45 in.^{2} = 0.3125 ft^2 (Assumption 1.1)

m_h = 1,013,310 lb_m/h = 281.48 lb_m/s (see the section above, Determine the slurry inlet temperature)

$$G_h = \frac{281.48\,lb_m\,/s}{0.3125\,ft^2} = 900.74\ lb_m\,/s\,ft^2$$

The velocity is obtained from Equation (14):

$$V = \frac{G}{\rho} = \frac{900.74\,lb_m\,/s\,ft^2}{(1.35)(62.4)\ lb_m\,/\,ft^3}$$

$$= 10.70\ ft\,/s$$

The viscosity is obtained from Equations (11), (12) and (13):

$$\mu = \frac{\tau}{\gamma}$$

$$\tau = \tau_o + \eta\gamma$$

τ_o = 30 Pa (Assumption 1.1)

η = 30 cP (Assumption 1.1)

$$\gamma = \frac{8V}{D_H} = \frac{8(10.70\,ft\,/s)}{0.210\,ft}$$

$$= 407.619\ s^{-1} \cong 408\ s^{-1}$$

$$\tau = \tau_o + \eta\gamma$$

$$= 30\,Pa + (30\,cP)(408\,s^{-1})(\frac{0.001\,Pa\,s}{cP})$$

$$= 30\,Pa + 12.24\,Pa = 42.24\,Pa$$

$$\mu = \frac{\tau}{\gamma} *1{,}000 = \frac{(42.24\,Pa)(1{,}000)}{408\,s^{-1}}$$

$$= 103.53\ cP$$

The apparent viscosity, μ, in lb_m/ft s is:

μ = 103.53 cP = 103.53(0.0006725) = 0.0696 lb_m/ft s

Then from Equation (8):

$$Re = \frac{GD_H}{\mu}$$

$$= \frac{(900.74\ \text{lb}_\text{m}/\text{s ft}^2\ )(0.210\ \text{ft})}{0.0696\ \text{lb}_\text{m}/\text{ft s}} \cong 2{,}718$$

The Prandtl number is determined by Equation (16):

$$Pr = \frac{\mu c_P}{k}$$

μ = 0.0696 lb_m/ft s
k = 0.36 Btu/hft°F
= 0.0001 Btu/s ft°F (Assumption 1.1)
c_p = 0.9 Btu/lb_m°F (Assumption 1.1)

$$Pr = \frac{\mu c_P}{k}$$

$$= \frac{(0.0696\ \text{lb}_\text{m}/\text{ft s}\ )(0.9\ \text{Btu}/\text{lb}_\text{m}\ °\text{F}\ )}{0.0001\ \text{Btu}/\text{s ft}\ °\text{F}}$$

$$\cong 626$$

The Nusselt number is determined using Equation (7):

$$Nu = 0.0239 \left(1 + 5.54 \frac{D_H}{R_M}\right) Re^{0.806}\ Pr^{0.268}$$

$$= 0.0239 \left(1 + 5.54 \frac{0.210}{0.698}\right) \bullet$$

$$(2{,}718)^{0.806}\ (626)^{0.268} \cong 210$$

Then from Equation (18), the film transfer coefficient for the hot fluid is:

$$h_h = \frac{k\, Nu}{D_H} = \frac{(0.36\ \text{Btu}/\text{h ft}^2\,°\text{F})(210)}{0.210\ \text{ft}}$$

$$= 360\ \text{Btu}/\text{h ft}^2\,°\text{F}$$

Calculate the film heat transfer coefficient for the cold side. The film heat transfer coefficient for the cold side is determined as follows:
From Equation (10):
$(D_H)_c \cong 2S_c = 2(0.25\ \text{in.}) = 0.50$ in. = 0.0417 ft ([Ref. 4, p. 16] and Assumption 1.1)

To determine the Reynolds number, the mass velocity is determined first from Equation (9):

$$G = \frac{m_c}{H S_c}$$

m_c = 150,120 lb_m/h = 41.7 lb_m/s (Assumption 1.4)
μ = 0.00082 lb_m/ft s (Assumption 1.10)

$A_c = HS_c = (36\ \text{in.})\ (0.25\ \text{in.}) = 9\ \text{in.}^2 = 0.0625\ \text{ft}^2$ (Assumption 1.1)

$$G = \frac{41.7\ \text{lb}_\text{m}/\text{s}}{0.0625\ \text{ft}^2} = 667.2\ \text{lb}_\text{m}/\text{s ft}^2$$

The velocity is obtained from Equation (14):

$$V = \frac{G}{\rho} = \frac{667.2\ \text{lb}_\text{m}/\text{s ft}^2}{62.35\ \text{lb}_\text{m}/\text{ft}^3} = 10.70\ \text{ft}/\text{s}$$

From Equation (8):

$$Re = \frac{GD_H}{\mu}$$

$$= \frac{(667.2\ \text{lb}_\text{m}/\text{s ft}^2\ )(0.0417\ \text{ft})}{0.00082\ \text{lb}_\text{m}/\text{ft s}}$$

$$= 33{,}930$$

The Prandtl number is determined by Equation (16):

$$Pr = \frac{\mu c_P}{k}$$

μ = 0.00082 lb_m/ft s (Assumption 1.10)
k = 0.336 Btu/h ft °F = $9.33(10)^{-5}$ Btu/s ft°F (Assumption 1.10)
c_p = 1.0 Btu/lb_m°F (Assumption 1.10)

$$Pr = \frac{\mu c_P}{k}$$

$$= \frac{(0.00082\ \text{lb}_\text{m}/\text{ft s}\ )(1.0\ \text{Btu}/\text{lb}_\text{m}\ °\text{F}\ )}{9.33(10)^{-5}\ \text{Btu}/\text{s ft}\ °\text{F}}$$

$$= 8.79$$

The Nusselt number is determined using Equation (7):

$$Nu = 0.0239 \left(1 + 5.54 \frac{D_H}{R_M}\right) Re^{0.806}\ Pr^{0.268}$$

$$= 0.0239 \left(1 + 5.54 \frac{0.0417}{0.698}\right) \bullet$$

$$(33{,}930)^{0.806}\ (8.79)^{0.268} \cong 255$$

Then from Equation (18), the film heat transfer coefficient for the cold fluid is:

$$h_c = \frac{k\, Nu}{D_H}$$

$$= \frac{(0.336\ \text{Btu}/\text{h ft}\ °\text{F})(255)}{0.0417\ \text{ft}}$$

$$\cong 2{,}055\ \text{Btu}/\text{h ft}^2\,°\text{F}$$

Calculate the overall heat transfer coefficient. The overall heat transfer coefficient is determined from

Equation (3):

$$U = \frac{1}{\frac{1}{h_h} + \frac{t}{k} + \frac{1}{h_c} + R_f}$$

$$h_h = 360\ \text{Btu}/\text{h ft}^2\,°\text{F} \Rightarrow \frac{1}{h_h}$$

$$= 0.00278\ \frac{\text{h ft}^2\,°\text{F}}{\text{Btu}}$$

$$h_c = 2{,}055\ \text{Btu}/\text{h ft}^2\,°\text{F} \Rightarrow \frac{1}{h_c}$$

$$= 0.00049\ \frac{\text{h ft}^2\,°\text{F}}{\text{Btu}}$$

t = 0.125 in. = 0.01042 ft (Assumption 1.1)
k = 8.4 Btu/h ft°F [Ref. 1, pp. 2–59]

$$\frac{t}{k} = \frac{0.01042\ \text{ft}}{8.4\ \text{Btu}/\text{h ft}\ °\text{F}} = 0.0012\ \frac{\text{h ft}^2\,°\text{F}}{\text{Btu}}$$

$$R_f = 0.0006\ \frac{\text{h ft}^2\,°\text{F}}{\text{Btu}}$$
(Assumption 1.12)

$$U = \frac{1}{\frac{1}{h_h} + \frac{t}{k_P} + \frac{1}{h_c} + R_f}$$

$$= \frac{1}{\left[\begin{array}{c}(0.00278 + 0.0012 + \\ 0.00049 + 0.0006)\dfrac{\text{h ft}^2\,°\text{F}}{\text{Btu}}\end{array}\right]}$$

$$= \frac{1}{0.00507\ \dfrac{\text{h ft}^2\,°\text{F}}{\text{Btu}}} \cong 197\ \frac{\text{Btu}}{\text{h ft}^2\,°\text{F}}$$

Calculate the length of the heat transfer plate. The total heat transfer is determined from the energy absorbed by the chilled water. Substituting in Equation (1), we have:
$Q = m_c\, c_c\, (T_{co} - T_{ci}) = 150{,}120\ \text{lb}_\text{m}/\text{h}$ (1.0 Btu/lb_m°F)(55–50)°F
=750,600 Btu/h
Using Equation (6):

$$L = \frac{Q}{2\, HU\,(LMTD)}$$

$$Q = 750{,}600\ \frac{\text{Btu}}{\text{h}}$$

H = 36 in. = 3 ft (Assumption 1.1)

$$U = 197\ \frac{\text{Btu}}{\text{h ft}^2\,°\text{F}}$$

(see the section above, Calculate the overall heat transfer coefficient)
$LMTD$ = 24.85°F (see the section

NOMENCLATURE

A	= Heat-transfer surface area, ft²		m_c	= Mass flowrate of cold fluid, lbm/h	
A_c	= HS = Flow area of channel, ft²		Nu	= Nusselt number, unitless	
C	= Core diameter, in.		Pr	= Prandtl number, unitless	
c_c	= Specific heat of cold fluid, Btu/lbm°F		ΔP	= Pressure drop, kPa (psi)	
			Q	= Total heat transfer, Btu/h	
c_h	= Specific heat of hot fluid, Btu/lbm°F		R_{max}	= Maximum radius of spiral, ft	
			R_{min}	= Minimum radius of spiral, ft	
c_p	= Specific heat of fluid, Btu/lbm°F		Re	= Reynolds number, unitless	
D_H	= Average hydraulic diameter of channel, ft		R_f	= Fouling factor, h°F ft²/Btu	
			R_M	= Mean spiral radius, ft	
D_s	= Outside spiral diameter, in.		S	= Channel spacing, ft	
G	= Mass flux, lbm/s ft²		S_h	= Spacing of the hot side, in.	
H	= Width of the plate, ft		S_c	= Spacing of the cold side, in.	
h	= Film heat-transfer coefficient, Btu/h ft² °F		t	= Thickness of the plate providing the heat transfer-surface, ft (in.)	
h_h	= Hot-side convection heat-transfer coefficient, Btu/h ft² °F		T_{ho}	= Outlet temperature of hot fluid, °F	
			T_{hi}	= Inlet temperature of hot fluid, °F	
h_c	= Cold-side convection heat-transfer coefficient, Btu/h ft²°F		T_{co}	= Outlet temperature of cold fluid, °F	
k	= Thermal conductivity of fluid, Btu/h ft °F		T_{ci}	= Inlet temperature of cold fluid, °F	
			ρ	= Density, kg/m³ (lbm/ft³)	
k_P	= Thermal conductivity of the plate providing the heat-transfer surface, Btu/h°F ft		τ	= Bingham plastic shear stress, Pa	
			τ_o	= Bingham plastic yield stress, Pa	
L	= Length of the plate, ft (m)		η	= Bingham plastic consistency viscosity, cP	
$LMTD$	= Log mean temp. difference, °F		γ	= Strain rate, s⁻¹	
m	= Mass flowrate, lbm/s		μ	= Apparent viscosity of fluid, lbm/ft s	
m_h	= Mass flowrate of hot fluid, lbm/h				

TABLE 1. RESULTS OF THE SAMPLE CALCULATION

Fluid	Hot-side slurry	Cold-side water
Volume flowrate, gal/min	1,500	300
Specific heat, Btu/lbm °F	0.9	1.0
Density, lbm/ft³	84.24	62.4
Specific gravity	1.35	1.0
Viscosity, cP	103.53	1.22
Thermal conductivity, Btu/ft h°F	0.36	0.336
Inlet temperature,°F	77.82	50
Outlet temperature, °F	77	55
Pressure drop, psi	16.95	12.83
Heat transfer Area, ft²	192	——
Heat exchanged, Btu/h	750,000	——
LMTD, °F	24.85	——
Heat transfer coefficient, Btu/h ft² °F	197	——
Percentage of over surface, %	25.32	——
Plate length, ft	32	——
Plate width, in.	36	——
Outside spiral diameter, in.	32	——

above, Calculate the LMTD)

$$L = \frac{Q}{2\,H U\,(LMTD)}$$

$$= \frac{750,600\,\text{Btu/h}}{2(3\,\text{ft})(197\,\text{Btu/h ft}^2\,°F)(24.85\,°F)}$$

$$= 25.6\,\text{ft}$$

$A = 2HL = 2(3\text{ ft})(25.6\text{ ft}) = 153.6\text{ ft}^2$

From Equation (2) the actual heat duty is:

$Q = U A\,(LMTD)$

$$= (197\frac{\text{Btu}}{\text{h ft}^2\,°F})(153.6\,\text{ft}^2)(24.85\,°F)$$

$$\cong 751,941\,\text{Btu/h}$$

It is shown that the actual duty is greater than the required operating duty by a very small amount. The percentage of over-surface design is:

$$OS = 100\left(\frac{\text{Actual duty}}{\text{Operating duty}} - 1\right)$$

$$= 100\left(\frac{751,941}{750,000} - 1\right) = 0.26\%$$

An over-surface design between 20 and 30% is specified (Assumption 1.13). Therefore, the length of the plate must be increased. Assuming a new value of 32 ft and repeating the calculation, the new heat transfer area is:

$A = 2H\,L = 2(3\text{ ft})(32\text{ ft}) = 192\text{ ft}^2$

And the new actual duty is:

$Q = U A\,(LMTD)$

$$= (197\frac{\text{Btu}}{\text{h ft}^2\,°F})(192\,\text{ft}^2)(24.85\,°F)$$

$$\cong 939,926\,\text{Btu/h}$$

$$OS = 100\left(\frac{\text{Actual duty}}{\text{Operating duty}} - 1\right)$$

$$= 100\left(\frac{939,926}{750,000} - 1\right) = 25.32\%$$

Thus, the over-surface design is between 20 and 30% as indicated in Assumption 1.13.

Calculate pressure drop for hot stream. Calculate the pressure drop for the hot stream using Equation (20):

$$\Delta P = \frac{1.45(LV^2\rho)}{1.705 \bullet 10^3}$$

Here:
$L = 32$ ft $\cong 9.80$ m (see the above section, Calculate the length of the heat transfer plate)
$S_g = 1.35 \Rightarrow \rho = 84.24$ lbm/ft³ = 1,320.05 kg/m³ (Assumption 1.1)
$V = 10.70$ ft/s $\cong 3.26$ m/s (see the above section, Calculate the hot side film heat transfer coefficient)

$$\Delta P = \frac{1.45\left[\begin{array}{c}(9.80\,m)(3.26\,\text{m/s})^2 \bullet \\ (1,320.05\,\text{Kg/m}^3)\end{array}\right]}{1.705 \bullet 10^3}$$

$$= 116.92\,\text{kpa} = 16.95\,\frac{\text{lb}_f}{\text{in.}^2}$$

Calculate pressure drop for cold

stream. The pressure drop for the cold stream is calculated using Equation (20):

$$\Delta P = \frac{1.45(LV^2\rho)}{1.705 \bullet 10^3}$$

Here:
L = 32 ft $\cong$ 9.80 m (see the section above, Calculate the length of the heat transfer plate)
ρ = 62.35 lb_m/ft^3 = 998.85 kg/m^3 (Assumption 1.10)
V = 10.70 ft/s = 3.26 m/s (see the section above, Calculate the film heat transfer coefficient of the cold side)

$$\Delta P = \frac{1.45\left[\begin{array}{c}(9.80\,\text{m})(3.26\,\text{m}/\text{s})^2 \bullet \\ (998.85\ \text{kg}/\text{m}^3)\end{array}\right]}{1.705 \bullet 10^3}$$

$$= 88.47 \text{ kpa} = 12.83\ \frac{\text{lb}_f}{\text{in.}^2}$$

Determine the outside spiral diameter. The diameter of the outside spiral is determined via Equation (21):
$D_s = [15.36L\,(S_h + S_c + 2t) + C^2]^{1/2}$
Here:
L = 32 ft (see the section above, Calculate the length of the heat transfer plate)
S_h = 1.25 in. (Assumption 1.1)
S_c = 0.25 in. (Assumption 1.1)
t = 0.125 in. (Assumption 1.1)
C = 12 in. (Assumption 1.1)
Then:
$D_s = [15.36L\,(S_h + S_c + 2t) + C^2]^{1/2}$
$= [15.36(32)(1.25 + 0.25 + 2(0.125)) + (12)^2]^{1/2}$
$D_s = [491.52(1.75) + 144]^{1/2} = [1,065.6]^{1/2} = 31.69 \Rightarrow$ Use 32 in. ∎

The results are shown in Table 1. ∎

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Agglomeration Technology: Equipment Selection

Bryan J. Ennis
E&G Associates, Inc.

Take more than product attributes into account when choosing agglomeration equipment

A virtually endless number of process options are available for agglomerating powders in the chemical process industries (CPI). These processes can be divided into two main categories: agitation and compression. Agglomeration by agitation includes granulation processes, such as fluidized-bed, disc, drum and mixer granulators. Agglomeration by compression includes compaction processes, such as tabletting, extrusion, roll presses and pellet mills. Process choice is affected by certain feed attributes as well as a host of ancillary decisions. This article focuses on equipment selection criteria for granulation and compaction processes. The mechanisms of agglomeration were reviewed in an earlier article [1], and additional detailed information on agglomeration is available elsewhere [2–7].

Wet granulation

Granulation processes vary from low to medium levels of applied shear and stress, producing granules of low to medium, and in some cases, high density [2]. Ranked from lowest to highest levels of shear, these processes include fluidized-bed, tumbling and mixer granulators. In wet granulation, agglomeration is promoted by the addition of binders and solvents.

Fluidized-bed granulators. In fluidized-bed granulators, particles are supported and mixed by a heated gas. This action also induces drying. Proper gas-distributor design is required to maintain solids mixing, heat and mass transfer, and to prevent unstable operation that could cause the bed to defluidize or collapse. Batch and continuous designs are available (Figures 1a and 1b), as well as spouted-beds and coaters. Liquid binder is sprayed through an atomizing two-fluid nozzle located above, in or below the bed. Both aqueous and solvent solutions are used, which requires solvent recovery con-siderations. Spray distribution, atomizer design and humidity control are crucial to proper operation. Bag filters or cyclones are needed to remove entrained dust from the exit air.

Batch processes in a wide range of batch sizes are used to agglomerate fine powder to produce high porosity granules. Alternatively, slurries of feed materials may be sprayed onto a bed of seed particles to produce high-strength, layered granules. Continuous fluidized beds, generally of a serpentine design, produce layered granules. Recycle of off-size material is very common and involves ancillary equipment for continuous classification, crushing and grinding. Seed material is often introduced to the initial stages to promote process stability. Spouted-bed designs are used for coating applications, as well as for precision granulation where growth is localized within the upward-conveying draft tube.

Tumbling granulators. In tumbling granulators, particles are set in motion by the tumbling action caused by the balance between gravity and centrifugal forces. Common designs include continuous, inclined disc and drum granulators (Figures 1c and 1d) with throughput ranges of 1–100 ton/h and 1–5-min residence times. Disc granulators consist of a rotating pan with a rim, typically tilted at horizontal angles of 50–60 deg. Drums consist of a cylinder, inclined at a horizontal angle of 3–10 deg, which may be either open-ended or fitted with annular retaining rings. Tumbling granulators generally produce granules in the size range of 1–20 mm and are not suitable for making granules smaller than 250 μm. Granule density generally falls between that of fluidized-bed and mixer granulators, and it is difficult to produce highly porous agglomerates in tumbling granulators.

Rotational speed and incline angle are set to maintain proper tumbling action. Solids are introduced continuously by volumetric or gravimetric feeders. Gravimetric feeding often improves granulation performance due to smaller fluctuations in feedrates. Such fluctuations act to disrupt the rolling action of the solids bed and can lead to poor distribution in moisture, agglomerate growth and local surface buildup of solids. Wetting fluids for growth are applied by a series of single-fluid-spray nozzles distributed across the face of the bed. Solids feed and spray nozzle locations have a pronounced effect on granulation performance and granule structure. Distributor-pipe feeding systems are used in drums with simultaneous chemical reaction (for example for fertilizers).

A key feature of disc operation is the inherent size classification. Centripetal forces throw small granules and ungranulated feed high onto the disc, whereas large granules remain in the eye and exit as product. Size segregation leads to exit of product granules only from the eye at the rim of the disc. This classification substantially narrows exit-granule size distribution, allowing discs to operate with little or no pellet recycle at a yield of 70–80% on the first pass.

Drums have no output size classification and high recycle rates of off-size product are common. Holdup in the drum is between 10 and 20% of the drum volume, with drum lengths ranging from 2–5 times the diameter. Drum granulation plants often have significant recycle ratios (2:1 to 5:1) of both undersize and crushed oversize granules. This large recycle stream has a major effect on circuit operation,
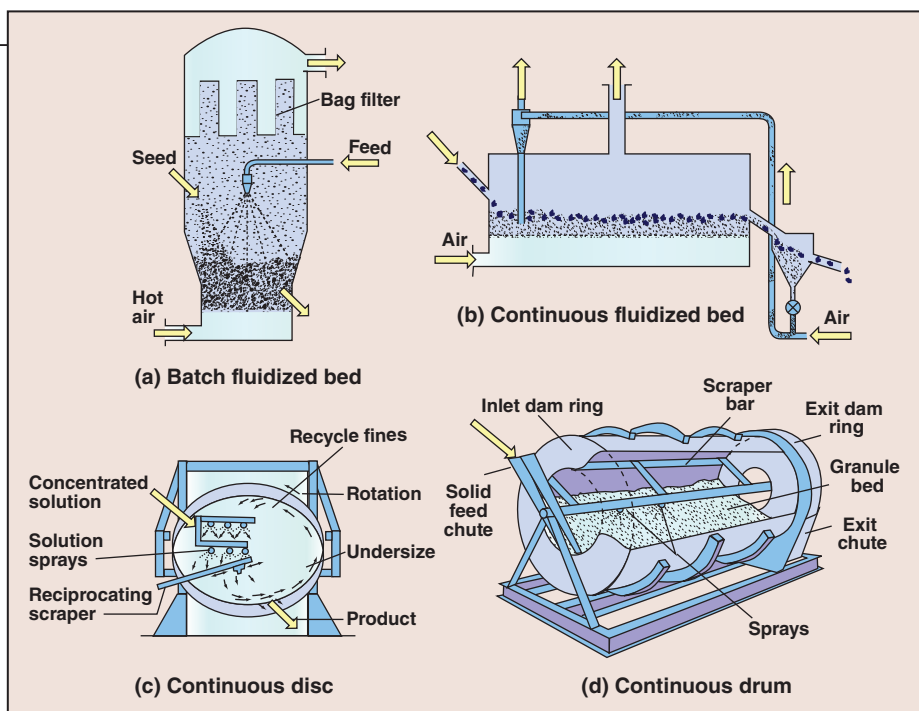
FIGURE 1. Low-shear granulation processes include both batch and continuous choices, such as the granulators shown here

stability and control. Surging of recycle streams and limited cycle behavior are common, which significantly affect granule exit-size distribution.

Mixer granulators. Mixer granulators induce granulation through mechanical agitation. A wide selection of mixing-tool designs is available. Differences in equipment, impeller and chopper geometry result in very wide variations in shear rate and powder flow patterns among manufacturers. Great caution should be exercised in transferring formulations and empirical knowledge between mixer designs. Further, geometric similarity is rarely maintained in scaleup because of some practical limitations with most commercial equipment. Controlling the amount of liquid phase, wet mass rheology, and the intensity and duration of mixing determines agglomerate size and density. Due to the strong compaction and kneading action in mixer granulators, this equipment produces denser, less spherical granules, typically with less liquid phase.

Low shear mixers include ribbon or paddle blenders, planetary mixers, orbiting screw mixers, sigma blade mixers and double cone or V-blenders that operate with rotation rates or impeller speeds less than 100 rpm. Both batch and continuous equipment are common. Mixing times in these granulators are quite long (20–40 min), and many low shear mixers are ultimately replaced with high shear mixers.

High speed mixers include continuous shaft mixers and batch mixers. Continuous shaft mixers have blades or pins rotating at high speed on a central shaft in both horizontal and vertical shaft designs (Figures 2a and 2b). Examples include the vertical Schugi mixer and horizontal pin mixers, which operate at high speed (200 to 3,500 rpm) with a residence time of a few seconds to produce granules of 0.5 to 1.5 mm. Intimate mixing is achieved. However, little time is available for substantial product growth or densification, and the granulated product is generally fine, irregular, and fluffy with low bulk density. Capacities may range up to 10–200 ton/h with power requirements of up to 200 kW. Continuous high-speed mixers are often followed by additional mixers operating at a higher residence time and lower shear to promote additional growth and densification.

Batch high-shear mixer granulators are valued for their robustness in processing a range of powders as well as the ease with which they can be enclosed and cleaned (Figures 2c and 2d). Plow shaped mixers rotate on a horizontal shaft at 60–800 rpm. Most designs incorporate an off-center high-speed cutter or chopper rotating at a much higher speed (500–3,500 rpm), which breaks down over-wetted powder mass and limits the maximum granule size. The scale range is 10–1,200 L with granulation times on

the order 5–10 min, which includes both wet massing and granulation stages operating at low and high impeller speed, respectively.

Granulator selection. Four key rate mechanisms contribute to all granulation processes [1, 3–7]. These are wetting and nucleation, coalescence or growth, consolidation and attrition or breakage. It is vital to keep in mind the high degree of interaction between granulation mechanisms, formulation properties and process equipment in making equipment selection. Batch fluidized beds can produce one of the lowest density granules, and are an example of low deformable growth. Low deformability processes are stable in that consolidation generally occurs on a slower time scale than growth, allowing more independent control of granule size versus granule density than is possible in high deformability processes. Growth rate is controlled by spray rate and bed moisture. Fluidized beds must operate in a droplet-controlled wetting regime (Figure 2 in Ref. 1). Small drop penetration times and low spray fluxes are required to prevent binder pooling and defluidization. Poorly wetting powders or binders of initially high viscosity are precluded. Consolidation of granules can be increased independent of growth through increasing bed height, bed moisture or process residence time. Simultaneous drying allows solidification of binder within a granule during the granulation time, which arrests the densification process allowing production of porous granules. However, with seed recycle and slurry sprays, it is also possible to produce much denser, layered granules. The inherent stability of low deformability processes allows considerable manipulation in granule properties and ease of scaleup.

At the other extreme are high shear mixers, where blades and choppers induce binder distribution and growth, producing medium to dense, irregular granules. Mixers operate as a deformable growth process, where in most cases it is difficult to control granule density independent of size. Mixers have an advantage in that they can process plastic, sticky or poorly wetting materials, and can spread viscous binders, operating in a mechanical dis-

person regime of wetting [1]. On the other hand, they may equally process powders of fast wet-in time and may benefit in this case from spray nozzles when operating with low spray flux. However, associated with the flexibility in processing a wide variety of materials, high shear mixers can be very difficult to scale up due to large shifts in the competition between growth and densification, wetting regimes, and powder mixing with batch size. Shifts in nucleation and growth mechanisms with scaleup are not uncommon, making it difficult to compare pilot studies with full-scale operation.

Tumbling granulators produce uniform, spherical granules, and lie between fluidized beds and mixers in terms of shear rate and granule density, operating between low deformable growth at small scale, and moving toward deformable growth at very large scale. They have the highest throughput of all granulation processes.

In the case of non-deformable growth (for example in fluidized beds and tumbling granulators), granule size typically progresses through rapid, exponential growth in an initial nucleation stage, through a transition stage and finishes with slow growth in a final balling stage (Figures 3 and 5 in Ref. 1). In the initial nucleation stage when the average size is less than a limiting granule size (referred to as D_c in Ref. 1), the granule size distribution typically widens. This increase in the width of the granule size distribution is in proportion to the average, mean size. When the mean size approaches D_c in the balling stage, the distribution then begins to narrow [10]. During growth, granule internal porosity often decreases with time as the granules are compacted. In this most common case, size is controlled by spray rate, bed moisture and mixing rate. Increasing speed, such as drum rotation rate, will speed growth due to higher collision rates and mixing. Growth is independent of the granule viscous Stokes number, binding fluid viscosity and granule inertia [1]. This independence of growth on inertia again makes scaling and operation of fluidized beds and tumbling systems easier than for their deformable growth counterpart of mixers.
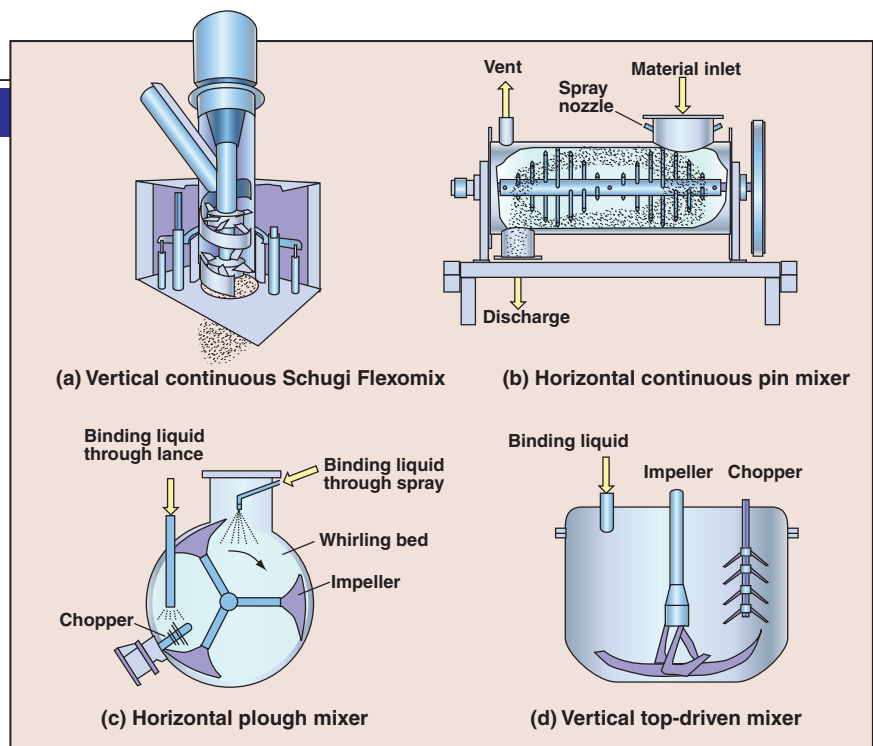
FIGURE 2. In high-shear mixers, blades, pins and choppers induce binder distribution and growth

The limit of growth in non-deformable systems varies inversely with viscous Stokes number [1]. Such limits are generally not achieved in fluidized beds, but may be achieved in tumbling granulators, especially in long drums with high residence time. In this case, it is possible for the size distribution to narrow if growth limits are approached. This maximum achievable size will increase with increasing binder viscosity, and decreasing granule density or rotation rate. Prior to this limit, size would increase with the number of rotations occurring with the given residence time. Therefore, one cannot predict the impact of rotation rate without knowing where in the growth profile the product exists.

In the deformable growth attained in mixers, two regions of operation may be identified — and it is absolutely vital that regions of growth be identified to appropriately control the process. For increasing deformation Stokes number, increases in impeller speed or decreases in formulation yield stress will increase growth rate in the initial, non-equilibrium region of growth, whereas the opposite holds true in the later, equilibrium growth. As with low-deformable processes, the size distribution generally widens in the non-equilibrium stage, but later may narrow as the limit of growth is achieved for the given impeller speed. Raising impeller speed in this later stage of growth will decrease size.

Note that increasing bed moisture acts to lower wet-mass yield stress and increase kneading, deformation and growth. And as pointed out, it is possible for shifts between equilibrium and non-equilibrium growth to occur between scales of operation [1, 4, 6].

Compaction and extrusion

Pressure compaction is carried out in two classes of equipment ([2] and Figure 3). These are dry processes (molding, piston, tabletting, briquetting and roll presses [8]), in which material is compacted between two opposing surfaces; and paste extrusion devices (pellet mills, screw extruders, table and cylinder pelletizers [9]), in which material undergoes considerable shear and mixing in the presence of a fluid carrier while being pressed through a die. Here, agglomeration is driven by mechanical deformation of the feed to achieve intimate packing of the feed particles.

Tablet presses. Tablet presses produce shapes of superior appearance with strict specifications in weight, geometry, hardness and dissolution behavior (Figure 3a). Molding presses operate at much slower rates and are used for more intricate shapes. Good flow properties are required for rapid, consistent die filling as well as proper die lubrication (low die friction) to prevent capping and delamination. For fine feeds this often requires a preprocessing operation of either wet granulation or dry agglomeration, which includes

for example, roll pressing or slugging.

Modern high-speed rotary tablet presses have dual feed-compression stages, and typically compress the tablet from both ends. Poor mechanical properties lead to a variety of flaws, including: delamination and capping; sticking to punch surfaces; localized cracks often due to recycled or hard materials; and poor tablet dissolution due to over-compacted regions.

Roll presses. Roll presses force material into the gap between two rotating rolls (Figure 3b) and provide a mechanical advantage, amplifying the incoming feed pressure to a maximum value that occurs at minimum gap. This maximum pressure and roll dwell time control agglomerate quality for given feed properties. Smooth or corrugated rolls produce solid sheets, which are subsequently broken down and classified to a desired agglomerate size range. The degree of confinement increases for opposing corrugated patterns that produce cigar-like agglomerates to pocketed rolls of briquetting presses (Figure 3c).

As flow properties and permeability decline, allowable roll feed and production rate will drop. This may be compensated by force-fed and vacuum-feed systems, wider rolls of smaller diameter and circumferential grooving of rolls. Multiple screw designs are effective in distributing the feed pressure for wide rolls. Forcing rolls beyond their permeability limited speed leads to erratic feeding and fluidization in the gap, and inconsistent granule quality. Nip pressure should be used for scaling granule quality and not roll loading. This maximum pressure controls sheet density and is a very strong function of friction and compressibility.

Extrusion. In extrusion, powder in a plastic state is forced through a die, perforated plate or screen. These processes can operate wet or dry to produce narrowly sized, dense pellets. Wet extrusion is often followed by spheronization techniques to round the product. Types of extruders include screw extruders (such as axial end plate, radial screen and basket designs), and pelletization equipment (such as rotary cylinder and ram extruders; Figures 3, d, e and f). Material undergoes substantial shear in the equipment, and operation, and product attributes are strongly influenced by the frictional interaction between the powder and wall. In ram extruders, material is directly consolidated between two opposing surfaces. Extrusion processes can exert the highest applied force of any size-enlargement device to give the highest density product.

In wet extrusion, wet mass rheology and friction control the pressure needed to induce die extrusion, and this pressure increases with desired throughput. The actual pressure that can be developed by the sliding action of the barrel is a decreasing function of throughput, and it increases with increasing barrel and decreasing screw friction. These relationships are referred to as the die and screw characteristics of the extruder, respectively [5]. Their intersection determines the operating point, or throughput of the extruder, which may shift with wear of dies, screws and barrels over equipment life due to changes in wall friction and die entrance effects. Lastly, the rheological properties of the liquid phase are equally important. Poor rheology can lead to separation of the fluid and solid phases, large rises in pressure, and undesirable shark-skin-like surface appearance on the granulate [5, 9].

Equipment selection. Process performance in extrusion and dry compaction equipment is very sensitive to powder flow and mechanical properties of the feed, and generally produces much denser compacts or agglomerates than wet granulation. As discussed previously [1], compaction improves with increased stress transmission (controlled by lubrication and die geometry), decreased deaeration time (increasing powder permeability and decreasing production rate), increased plastic/permanent deformation and increased powder flowability. These features impact process selection to varying degrees [2].

In the case of dry compaction, the compaction pressure must exceed the inherent hardness of the material. Therefore, the necessity to form permanent bonds following stress unloading makes it difficult to process brittle, hard materials. Appropriate binders can be added, or wet extrusion/pellet mills used. Small amounts of moisture are common. It must be kept in mind, however, that the incompressibility of the fluid can limit the maximum achievable density and strength of the compact. Abrasive materials cause substantial equipment wear and may require special materials of construction. Elastic materials may also present problems in dry compaction, especially tabletting, as large elastic recovery promotes flaw development. Alternatively, abrasive, hard, brittle, elastic materials can be processed in wet granulation equipment provided that lower density and the additional operating and investment costs of drying are allowed (also required in wet extrusion). On the other hand, non-wetting materials are easily processed in compaction processes, which is not the case in wet granulation with the exception of high shear mixers.

Wall friction impacts both stress uniformity, as well as developed pressures in wet extrusion. In the case of unconfined roll pressing, high friction is often desirable to pull material into the rolls with greater force. However, for tabletting, wall friction angles greater than five degrees often lead to non-uniform compact stress, capping and delamination. In addition, the required pressure, ejection forces and likelihood of flaw development in tablets increase with increasing wall friction. This generally requires the addition of lubricants to aid tabletting. Briquetting machines and patterned rolls fall between these cases, dependent of pocket design. In the case of wet extrusion, high barrel friction, low screw friction, and low die friction is desirable for developing large die-face pressures, which controls die extrusion rate.

If large powder deaeration is required, increased air entrapment may occur within the die or feed zone, resulting in lowered feed and production rates, and increased flaw development due to gas pressurization within the compact. Either low permeability, or materials undergoing large void volume changes, will exacerbate this problem. In the case of roll pressing and wet extrusion, this may be addressed by vacuum and forced fed systems or other deaeration allowances, increased dwell time, or increased recycle rate. In the case of tabletting, however, this is generally handled ei-

ther by upstream wet granulation or roll pressing to produce a denser, free flowing feed. Such two-stage densification systems are common for fine, low permeability materials, an example being high recycle roll pressing.

As compaction processes are inherently continuous, powder feedrate is critical. Flowrate into die chambers and through clearances is generally a very strong function of diameter. Erratic flow is possible for cohesive, low permeability powder. Little allowance is possible for tabletting except two-stage processing, for example upstream agglomeration to improve flow. In the case of rolls, forced or vacuum feeding, increased dwell time, and wider rolls of smaller diameter provide some relief.

Overall considerations

The choice of agglomeration equipment is subject to a variety of constraints and should ideally be made on the basis of the desired final product attributes and special processing requirements (such as heat and moisture sensitivity [2]). In practice, however, there are many other considerations that include a company's historical process experience with a given technology, operating and investment costs, local availability and cost of key ingredients and utilities, retrofitting and building considerations, ease of dust containment and ease of equipment cleanout.

Agglomerate porosity and size distribution control agglomerate end-use properties and are important first considerations, along with agglomerate appearance and the ability to utilize moisture or solvents. Wet granulation produces low- to medium-density granules of varying sphericity. Binders are typically utilized, and drying of solvents is required, with the associated energy and dust/air handling costs. If denser agglomerates are re-
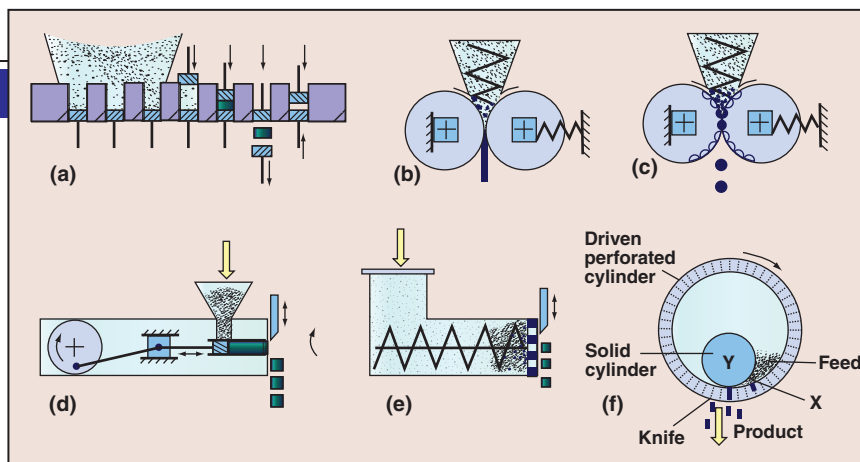
FIGURE 3. Examples of compressive agglomeration include: For dry compaction, (a) tabletting, (b) roll pressing, (c) briquetting, (d) ram extrusion; and for paste extrusion, (e) screw extrusion and (f) concentric-roll pelletizing

quired, dry compaction or wet extrusion should be considered, although it is worth noting that reasonably dense granules are possible with two-stage mixer processing. Dry compaction is suitable for moisture sensitive materials. Appearance considerations might suggest tabletting, or wet granulation (fluidized bed, drum, pan) or extrusion combined with spheronizing for free-flowing, nearly spherical granules.

Various technologies have feed material limitations. With the exception of high shear mixing, wet granulation requires wettable formulations whereas this is not a concern in compaction. On the other hand, hard, brittle, abrasive, elastic materials are difficult to process in dry compaction and can present equipment wear problems in wet extrusion. These mechanical properties do not present any limitation in wet granulation, outside of increased attrition rates. Lastly, materials of low permeability can present limitations in continuous processes, especially in dry compaction, as discussed above.

Heat, solvent or pressure sensitivities may preclude a process. An example would be the stability of polymorphs. High frictional heating is possible in mixing, as well as pressure sensitivity in all compaction and extrusion processes. Moisture or solvent may already exist in the powder, for

example in wet cakes, making drum tumbling and wet extrusion processes attractive. In some cases, simultaneous reaction is desired, which is possible in high shear mixing, drum and wet extrusion processes. One-pot processing, encompassing mixing, granulation and drying make both fluidized beds and mixers attractive choices. Pre- and post-processing requirements must be determined, and in this regard, the level of recycle that can be tolerated is an important consideration. As an example, drum wet granulation and dry roll pressing often require high levels of recycle for successful operation, and this can present issues of product degradation. Lastly, each process has unique sensitivities to fluctuations in raw ingredient properties, as well as the ease of scaleup. Ranking equipment from best to least forgiving with regard to tolerance to ingredient fluctuations gives: fluidized bed, tumbling (pan and drum), mixer, wet extrusion, tabletting, and roll pressing processing. ■

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Author

Bryan J. Ennis is president of E&G Associates, Inc. (P.O. Box 681268, Franklin, TN 37068; Phone: 615–591–7510; Email:bryan.ennis@ powdernotes.com), a consulting firm that deals with particle processing and product development for a variety of industrial and governmental clients. Ennis is an agglomeration and solids handling expert, who has taught over 75 engineering workshops in the last 25 years. He received his B.S.Ch.E. from Rensselaer Polytechnic Institute and his Ph.D. from The City College of New York. Ennis is the editor of Section 21: Solid-Solids Operations & Equipment of the "Perry's Chemical Engineers' Handbook" (8th ed.) and a contributor to several other powder technology handbooks. He served as an adjunct professor at Vanderbilt University, and his honors include two national awards from AIChE for service to the profession and founding of the Particle Technology Forum. Ennis also runs bi-annual continuing education workshops in solids handling, wet granulation and compaction, and powder mixing as part of the E&G Powder School (www.powdernotes.com).

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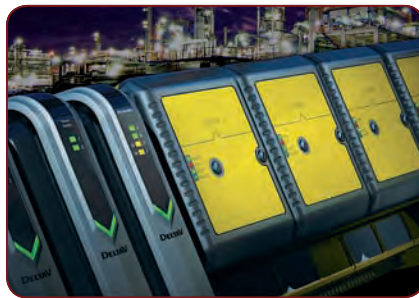
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Mustang provides highly experienced process engineers and project managers for all types of process projects, including automation and control

Mustang has wide-ranging experience on chemical and polymer projects, with a project management team whose members average more than 25 years in the process industries. Similarly, Mustang's process engineers average more than 20 years on these types of projects. Behind the scenes, the company boasts superior support teams and the latest 3D modeling techniques, including in-house laser scanning capabilities, to streamline projects and reduce costs.

Mustang can manage projects from conception through to operations. With its proven processes and focus on safety, it executes projects that come in on budget, on time and without surprises. Mustang personnel have experience in most of the licensed petrochemical, chemical and polymer processes used today. The company's expertise allows it to assist clients with the introduction of "first of a kind" or licensed technologies. Mustang offers technical and economic studies, technology evaluation, experimental program design, pilot plant programs, and acquisition of physical and chemical property data.

Mustang's Automation and Control group adds still another dimension to Mustang's total project capabilities on behalf of its clients. An experienced team with extensive process knowledge provides a vendor-independent approach with cost-effective and workable solutions for complex IT, automation and control projects. Front-end definition is a forte of the team, combined with innovative tools and methodologies that allow Mustang to be a full service provider of automation integration services, including advanced process control and abnormal condition management.

Mustang supports its projects with planning, established procedures and proven best practices. The company uses its own stage gate process (Stage COACH) and a proprietary project management tool (PACESETTER) to ensure that projects are successful from start to finish.

Mustang was founded in 1987 in Houston, Texas. Today the company has more than 3,500 employees with offices in the US, UK, Australia, India, Malaysia and the Middle East. Mustang has completed over 7,000 projects for more than 350 clients. **www.mustangeng.com**

Mustang has now completed more than 7,000 engineering projects

Plate heat exchangers in a wide variety of types

Tranter's plate heat exchangers are not limited to plate-and-frame or welded-plate designs; they also include spiral, shell-and-plate and prime-surface types

Tranter plate heat exchangers include (l–r) spiral, gasketed-plate, welded-plate, prime-surface, and shell-and-plate

Optimum performance in heat transfer is a promise **Tranter, Inc** has been fulfilling for many decades. For Tranter, heat transfer is not one of many focuses, it is the only focus. There is no problem in meeting heat transfer needs with proven products such as Tranter's prime surface product Platecoil, gasketed plate exchanger Superchanger, plate exchangers Supermax and Maxchanger as well as spiral heat exchangers. Tranter's complete engineering and manufacturing expertise result in equipment which meets the highest standards of design excellence and quality workmanship.

With the versatile line of products shown above, Tranter heat transfer products have seen service in many industries and have been used in myriad applications:

- vessel heating;
- heat recovery from boiler blowdown;
- jacket water cooling in black liquor recovery process;
- waste heat recovery from condenser water;
- heating or cooling jacket fluid for chemical reactors;
- heating and cooling chemical solutions;
- heat recovery from lean to rich amine solutions;
- multifunction units for condensing and mist elimination;
- gas condensation with hygienic design
- vapor and solvent recovery; and
- product heat and maintain for barges.

Tranter, Inc designs and manufacturers heat transfer products at several locations around the world. In the US, the manufacturing facility is located in Wichita Falls, TX. Tranter also has a sales office and refurbishment center located in Houston, TX, and refurbishment centers in Tulare, CA, Farmersville, IL, and Edmonton, AB.

www.tranter.com

Stop wasting valuable MP steam for heating duties

Back-pressure often restricts the use of cheap low-pressure steam—a problem solved by the PowerTrap combined steam trap and pump from TLV Corp.

Many refineries and petrochemical plants use costly medium-pressure (MP) steam for low-temperature heating duties, notes **TLV Corp.**, when they could instead be using cheaper and more readily available low-pressure (LP) steam. Alternatively, plants may use LP steam for heating, but waste energy by sending the

Steam power: TLV's PowerTrap works at line pressures up to 200 psig

condensate to drain. TLV's PowerTrap, a combined steam trap and pump, avoids both these problems by returning LP condensate to the boiler house even against significant back-pressure.

LP steam is a versatile heat source that is so abundant on many process plants that it is frequently vented to atmosphere, wasting its valuable energy content. MP steam, on the other hand, is scarcer and more expensive to produce, sometimes to the point where MP steam demand is made up by letting down high-pressure steam—a very wasteful operation.

So why is MP steam often used for low-temperature heating duties in reboilers, exchangers, jacketed vessels and preheat coils? A common reason is that if there is significant back-pressure in the condensate return system, the pressure of the LP steam is too low to drive condensate through a steam trap and into the condensate main. Instead, the system stalls: condensate backs up in the equipment and impedes heat transfer.

The typical way around this problem is either to use MP steam for heating, or to use LP steam and dump the condensate to drain. Either way, energy is wasted.

A much better way to use LP steam for heating when back-pressure is high is to install a TLV PowerTrap, a combination of a steam trap and a steam-powered condensate pump.

The PowerTrap optimizes process heating equipment performance by ensuring continuous drainage of condensate from equipment at steam pressures between vacuum and 200 psig.

It reduces energy costs by allowing plentiful LP steam to be used for process heating, avoiding the need to dump condensate or use costly MP steam instead.

The PowerTrap also improves the availability and reliability of process systems. It reduces channel head gasket damage, and eliminates cavitation or seal leakage issues often experienced with electric pumps, says the manufacturer.

www.tlv.com
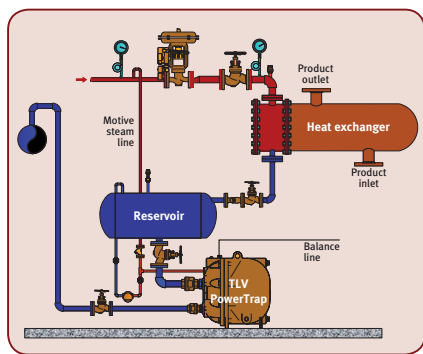
These rupture discs are good for 250,000+ cycles

Continental Disc unveils its newest reverse-acting rupture disc, with proven performance in excess of 250,000 cycles

Continental Disc Corp. has launched the new HPX and HPX SANITARY rupture discs at INTERPHEX 2010 in New York City, New York. The HPX rupture discs are scored reverse-acting discs that can be pressurized from full vacuum up to 90% or 95% of the rated (marked) burst pressure under normal operating conditions. These high-precision rupture discs offer proven performance in excess of a quarter million cycles.

The HPX and HPX SANITARY rupture discs are differential pressure relief devices that provide an instantaneous full-open, non-reclosing design for protecting equipment, vessels, systems and people from overpressure conditions. "The high cycling aspect of these rupture discs represents high performance to the extreme," says Steven Breid, Vice President of Sales and Marketing for Continental Disc. "Customers can choose 90% or 95% operating ratio depending on their process's requirements and budget."

Both rupture discs are also highly ver-

Long life under pressure cycling conditions is a prime feature of the new HPX and HPX SANITARY rupture discs

satile and offered in a wide range of burst pressures, materials and sizes. The HPX SANITARY rupture disc is designed specifically for the pharmaceutical, biotech, food and beverage industries. With a response time measured in milliseconds, this rupture disc meets all ASME BPE criteria including a surface finish of 20

microinch R_a or better and a solid metal construction providing cleanability for CIP/SIP applications. The HPX SANITARY rupture disc includes sanitary, environmentally friendly, non-toxic packaging.

Established in 1965, Continental Disc Corp. is a leading manufacturer of rupture disc devices for a variety of process industries, including chemical, petrochemical, petroleum refining, pharmaceutical, beverage, food, dairy, aerospace, gases, electronics, and other markets worldwide.

www.contdisc.com

Breathe easier with this high-pressure loop system

The HPLS from Total Safety is a high-pressure mobile breathing air system with many advantages over 6- or 12-bottle cascade systems, especially for large projects

Staying compliant is critical to the safety of your workers and to the success of your operation. **Total Safety**'s breathing air solutions, specifically its exclusive, patented High Pressure Breathing Air Loop System (HPLS) help ensure safety, compliance and efficiency during critical path turnarounds.

While traditional breathing systems utilizing 6- or 12-bottle cascades are appropriate for some functions, they can lower productivity and increase costs.

Compared to traditional breathing systems, the patented HPLS:
• greatly reduces manhours and lost time;
• increases efficiency;
• reduces costs; and
• increases safety.
Total Safety's HPLS reduces lost time and manpower expense and increases efficiency by creating the ideal respiratory environment for projects requiring high quantities of Grade D breathing air, including:
• permit-required confined space entry;

• asbestos or insulation removal;
• high-pressure hydro-blasting/cleaning;
• welding with exotic metals; and
• working in inert atmospheres.
Since Total Safety's HPLS is a closed continuous loop of breathing air, there's no need for cascade systems. This saves money by eliminating up-front material costs, and saves time by reducing work stoppages for fewer bottle change-outs.

Because Total Safety's tube trailers and air compressors operate outside the unit, plant traffic and congestion decrease. This makes for a safer working environment. What would normally take a lot of people now only requires a few, which saves thousands of man hours in a typical turnaround/outage.

For mid- to large-size projects, HPLS is completely flexible and customizable to fit your needs.

Total Safety is strategically located in more than 70 locations in 10 countries, fulfilling its mission to ensure the wellbeing of workers worldwide. Whether you need
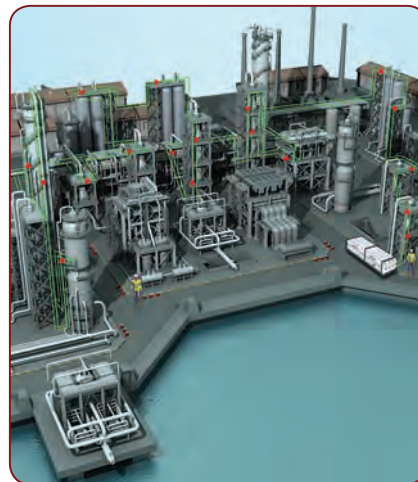
Big projects, big savings with HPLS

expert on-site safety services or competitive rates on equipment rentals and sales, Total Safety is ready for anything.
TotalSafety.com

Heat transfer fluids for the oil and gas industry

Therminol heat transfer fluids from Solutia are widely used in refining, gas processing, oil and gas pipeline operations, and reprocessing used lube oils

Therminol heat transfer fluids from **Solutia** are commonly used in offshore and onshore oil and gas processing, fractionation, refining, transportation, and recycling operations. Therminol 55, Therminol 59, Therminol 62, Therminol 66 and Therminol VP1 have successfully demonstrated low-cost, reliable, and safe performance in these applications for decades. Therminol fluids are selected because they provide lower capital and operating costs, and better temperature control, than other heat transfer options.

In gas processing and fractionation,

Therminol fluids are frequently used to heat gases for regenerating solid desiccants (such as molecular sieve) in gas dehydration beds; to reboil liquid desiccants (such as glycols) used for gas dehydration; to regenerate liquid solvents (such as amines) used for gas sweetening; to heat gas stabilization and NGL fractionation reboilers; and for other gas processing operations.

In oil processing and refining, Therminol fluids are often used to enhance oil/gas/ water/sediment/salt separation and for other processing and refining

operations such as low-sulfur gasoline production, solvent extraction, and sulfur recovery.

Therminol heat transfer fluids have applications in transportation too. Pumping stations along oil and gas pipelines often require heating to control the viscosity of oil streams, and to prevent condensation of components from gas streams. Therminol heat transfer fluids have proven capable of meeting these requirements in virtually any environment.

And the reprocessing of used lubricating oils involves operations at very high temperatures and high vacuum, for which Therminol heat transfer fluids are ideal. A variety of Therminol fluids are available with low vapor pressure, high thermal stability, and good heat transfer performance, supporting process needs at virtually any temperature.
www.therminol.com

www.therminol.com

THERMINOL
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FOR YOUR PEOPLE — Start-Up Assistance — Operational Training — Technical Service Hotline
FOR YOUR FACILITY — System Design — Quality Therminol Products — Sample Analysis — Flush Fluid & Refill — Fluid Trade-In Program*

Therminol TLC Total Lifecycle Care is a complete program of products and services from Solutia designed to keep your heat transfer system in top operating condition through its entire lifecycle.

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The expert source for rental energy solutions

Aggreko supplies rental equipment and services for temporary process cooling, climate control, power generation, and compressed air

Cooling towers and generators are among the equipment available

Aggreko's proven experience and innovation have made it the premier resource for rental energy solutions for the petrochemical and refining industries. Drawing on vast industry-specific knowledge, the company develops custom solutions to meet the challenges of turnarounds, shutdowns and general maintenance, including process, operational and environmental constraints.

Aggreko Process Services (APS) consists of an experienced process engineering team. It can design and install process enhancement solutions within a matter of weeks, rather than the months required for a typical capital project. This enables customers to capture short-run market opportunities. APS specifically targets process limitations caused by high ambient temperatures and fouled or under-performing equipment.

To address the demands for emergency or supplemental cooling at refineries, factories or other plants, Aggreko Cooling Tower Services (ACTS) was created. It provides 24-hour availability of the largest fleet of modular cooling towers in the industry, and enables operations to keep running smoothly during emergencies or maximize production while reducing the risks inherent in process cooling. Additional benefits of ACTS include:
- maximize production during hot summer months or peak demand times;
- maintain production while repairing or maintaining existing cooling tower;
- reduce costly downtime after disaster strikes; and
- meet or exceed customers' own environmental and safety standards.

Whether providing rapid emergency response to equipment failures or vessel cooling services to increase production, Aggreko is committed to delivering the highest performance standards 24/7/365. Aggreko keeps production and profitability flowing while delivering valuable time and cost savings, thanks to its experience, skill and specialized equipment.

www.aggreko.com/northamerica

Reliable and economical under extreme conditions

The new Pro-Flo X air-operated diaphragm pump from Wilden can be adjusted easily to give either maximum throughput or minimum air consumption
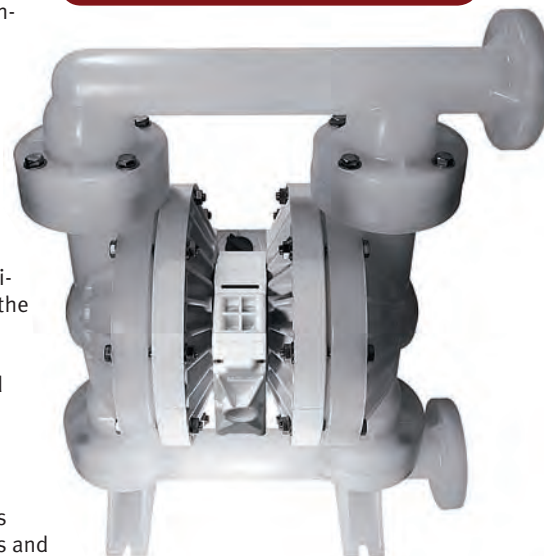

Powerful pumping: Wilden's Pro-Flo X

The Advanced bolted Pro-Flo X pump from **Wilden** is a reliable and economical solution for emptying vessels, filling tank cars, and transferring bulk chemicals quickly and safely. This new pump is designed to excel under extreme conditions. The bolted configuration ensures product containment, while the Pro-Flo X air distribution system (ADS) with its Efficiency Management Systems (EMS) allows the pump user to control flow rates and air consumption with the simple turn of a dial.

The Pro-Flo X technology makes the previously restrictive rules for air-operated double-diaphragm pump use obsolete. By adjusting the patent pending EMS dial to your exact process requirements, the Pro-Flo X ADS will exceed your expectations without breaking the bank. The pump performance can either be maximized to achieve a greater flow to get the job done fast, or you can maximize efficiency to reduce the operating cost of the pump.

The Advanced Pro-Flo X pump provides reliability, flexibility and efficiencies needed in today's energy-conscious and performance-driven applications.

www.wildenpump.com

A versatile range of emergency relief vent valves

These new manway pressure and pressure/vacuum relief vents go well beyond the performance of normal pressure relief systems, says manufacturer Valve Concepts

The new VCI 8900 Series from **Valve Concepts, Inc.** (VCI) provides the versatility that comes with innovative design and modular construction. Available in both top-guided (spring-loaded) and hinged (weight-loaded) configurations, 8900 Series relief vents feature a one-piece flange base with an integrated bolting pad to accommodate the hinged design. The modular design allows the valves to be converted from a pressure/vacuum vent to a pressure-only vent or vice versa.

"The design also permits the pressure pallet assembly to be easily removed for unobstructed access to the tank for cleaning, inspection or repairs," says Aaron Brantley, VCI product engineer. "Plus, the flange base incorporates a set of integrated lifting lugs for easier removal or installation."

Unlike competitive emergency pressure relief vents that use an O-ring for sealing,
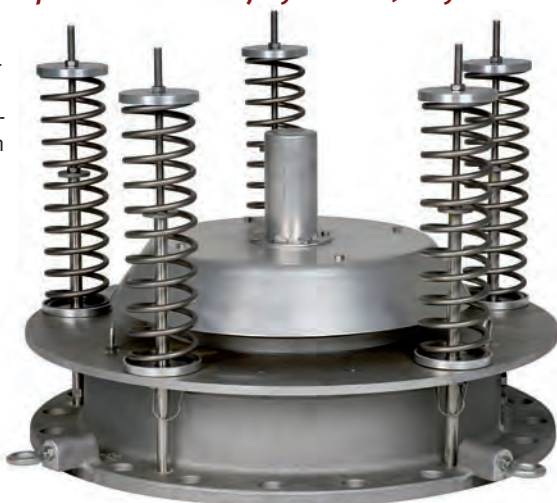
Modular design makes the VCI 8900 a versatile pressure/vacuum relief valve

8900 Series units utilize a flat diaphragm, which forms around the seat to provide a tighter seal and improved reliability. "The pressure pallet assembly provides an effective vapor-tight seal when the tank is not under emergency conditions," Brantley continues, "and after the excess pressure is relieved, the pallet assembly will reseat to again provide a vapor-tight seal."

Relief pressure on the hinged Model 8930 pressure relief vent and Model 8940 pressure/vacuum relief vent can be adjusted to <0.5 psig by adding or removing lid weights and counter-balance weights in any combination. The top guided Model 8910 pressure relief vent and Model 8920 pressure/vacuum relief vents can be adjusted from 0.5 to 15 psig by simply tightening or releasing spring pressure. All models are available with 20-inch or 24-inch ASME and API flanged bases, with other designs on request.

VCI, a division of Cashco, Inc., is headquartered in Ellsworth, Kan. Cashco manufactures a broad line of throttling rotary and linear control valves, pressure reducing regulators and back pressure regulators. **www.cashco.com**

Peak performance from this new gasket material

Flexitallic's Thermiculite gasket material combines peak performance with environmental safety, avoiding some of the drawbacks of graphite

The search for an effective alternative to traditional mineral fiber material in sheet gaskets has often been an exercise in frustration. Once-promising graphite has shown mixed results, especially at higher temperatures in oxidizing environments. When the carbon in graphite reacts with atmospheric or process oxygen to form carbon dioxide (O_2 (gas) + C(solid) $\dashrightarrow CO_2$ (gas)), oxidation occurs. In addition, naturally occurring impurities cannot be refined from raw graphite, creating another set of performance problems.

Some gasket manufacturers have attempted to compensate by incorporating oxidation-inhibitor additives into their graphite-based products, but these stop-gap measures have been effective only at delaying – not eliminating – the eventual effects of time and temperature.

The most promising alternative to traditional mineral fiber materials and graphite has been Vermiculite-based materials. Vermiculite is a hydrated lamellar mineral composed of aluminium-iron magnesium

silicate. Unlike the traditional mineral fiber (an aluminosilicate fiber) Vermiculite is a plate structure: non-oxidizing, capable of exfoliating, thermally stable and fire-safe, with broad chemical resistance and a plate-shaped primary particle—all excellent properties for gasket raw materials.

Flexitallic, a company with U.S. headquarters in Deer Park, Texas and manufacturing plants in the U.K. and China, has used the remarkable properties of Vermiculite to develop Thermiculite, a gasket material that seals as effectively as traditional mineral fiber materials and more effectively than graphite
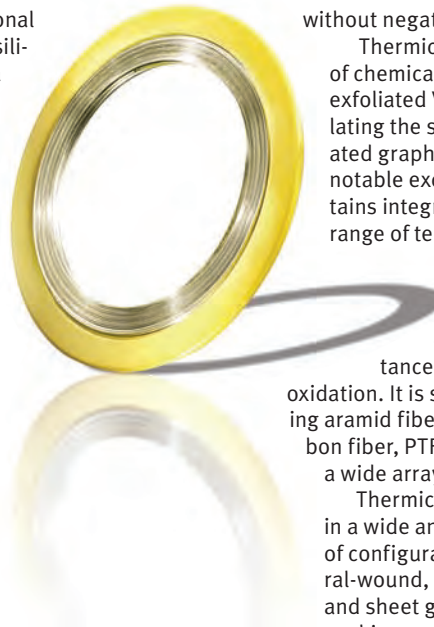
without negative consequences. Thermiculite is composed of chemically and thermally exfoliated Vermiculite, simulating the structure of exfoliated graphite with some notable exceptions – it maintains integrity through a wide range of temperatures, from moderate to extreme, and it maintains broad chemical resistance and freedom from oxidation. It is suitable for replacing aramid fiber, glass fiber, carbon fiber, PTFE and graphite in a wide array of applications.

Thermiculite is available in a wide and flexible array of configurations, from spiral-wound, serrated metal and sheet gaskets to braided packing.

www.flexitallic.com

Increasing business productivity in fuel additives

A leading manufacturer of diesel fuel additives is using Microsoft technology to streamline its business processes

Microsoft Dynamics®

Power Service (Weatherford, Texas; www.powerservice.com) manufactures some of the world's leading diesel fuel additives. Product uses range from preventing diesel fuel from freezing in cold-weather environments to improving the performance of biodiesels, often laden with impurities. Power Service sells its products through major retailers and wholesale distributors to clients that range from freight businesses and truckers to the military and even automobile hobbyists.

To manage the sale and distribution of its products to these retailers, Power Service needed a solution that supported all their business functions: accounts payable, accounts receivable, order processing, and billing. To control costs and establish an agile IT environment that could more easily adapt to changing business requirements, Power Service wanted to implement a solution that its IT staff could support and customize in-house while replacing the functions within their previous systems.

Power Service decided on **Microsoft Dynamics NAV** to maximize their existing technology investments. Employees access business data through a role-tailored user interface on their enterprise resource planning (ERP) system, running on a Microsoft SQL Server database. A single Role Center maps graphically to the company's entire order-processing workflow—from initial sale to shipment—to give employees access to the exact information they need to perform their specific jobs. As orders are processed, there are visual clues to show released orders, approved orders, and, eventually, open warehouse shipments. Warehouse staff manage items from those released, to picked, and then staged for shipment. Returned items and routine inquiries are accessed through the same interface. Via the internet, employees can view sales, reports, or drill into the data by leveraging Microsoft Office SharePoint Server from any web-connected PC.

Power Service now has a flexible solution in place to respond quickly to changing business needs while increasing productivity through the intuitive Role Center. Their IT department saves nearly 50% versus using third party support. As a result, they have been able to support annual double-digital sales growth without adding staff. With a solution tailored to its business, yet flexible to change, Power Service now has a system that complements their growth plans.

**www.microsoft.com/dynamics/en/us/ industries/chemical-manufacturing.aspx**

Simulators go online for better control and training

Simulators are not just for design, anymore! Models in CHEMCAD can link to control systems and even custom operator training simulators

Chemstations' simulator CHEMCAD is used worldwide to model processes from many industries, including ethanol production, natural gas operations, separations of specialty chemicals, refining, even carbon capture. Recently, many of our customers have been focusing on alternative energy such as biodiesel, alternative fuels, fuel cells, and solar cells.

While traditional process simulation is the major part of our business, emerging trends show that integration of a process simulator with other engineering software tools is the way of the future. Online control use is the first wave of integration.

Process simulators are used to create first-principles models (mass and energy balances) of a chemical process. Typically process simulators are used by engineers who are either designing a new facility, or trying to improve (or better understand) operation of an existing facility. Dynamic process simulation models allow for the operation of a virtual plant, with control systems.
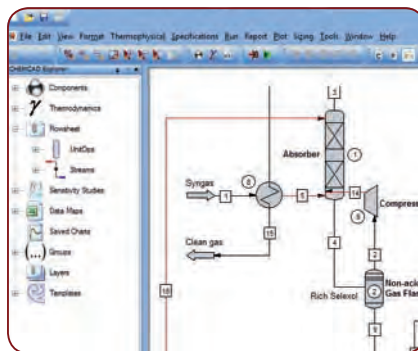
Chemstations: Integrating simulators with other engineering tools is the future

Many control systems rely on limited information from the plant. Flowmeters, thermocouples, and pressure sensors do not provide everything you want to know. Users of CHEMCAD have found that a process simulator can help bridge the gap between unknown and known for their control systems.

CHEMCAD accepts connections from COM, Excel, and OPC. This allows connection to other programs, control systems, even SCADA/HMI displays. CHEMCAD users have successfully connected simulations to control systems, external control, even SCADA/HMI displays for operators. Historical process data has been used to validate models before using the simulator online to predict current (and future) performance. Data reconciliation allows the simulation to adjust itself based on current sensor data.

Now engineers can take the process simulation model they built for engineering work and integrate it with their control system. When sensor data is used with a process simulation, the result can be a realistic prediction of unknown data. Want to be able to quickly predict liquid composition? Curious what the heat transfer coefficient (or fouling) is at an exchanger? A process simulator can help answer these questions, online.

www.chemstations.com

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(please answer all the questions)

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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

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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
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BUSINESS NEWS

PLANT WATCH

Air Liquide plans four new oxygen units for China

April 19, 2010 — Air Liquide (Paris, France; www.airliquide.com) has signed two contracts to supply four air separation units (ASUs). Air Liquide Hangzhou, the Engineering & Construction center in China, will supply two ASUs, each with a production capacity of 1,400 metric tons per day (m.t./d) of oxygen for the Yulin Energy and Chemical Corp. of Shaanxi Yanchang Petroleum Group. These new ASUs will supply oxygen for a new clean coal technology. Air Liquide will also supply two ASUs, each with a production capacity of 2,100 m.t./d of oxygen for the Shandong Hualu Hengsheng Group. These new ASUs will be installed to supply oxygen to coal gasification units at a new acetic acid plant.

Outotec to deliver technology for Bhushan Power & Steel Plant

April 17, 2010 — Outotec Oyj (Espoo, Finland; www.outotec.com) plans to deliver pelletizing technology to Bhushan Power & Steel Plant Ltd. (BPSL) for BPSL's steel plant expansion at Jharsuguda, located in India. Outotec's solution covers engineering and supply of proprietary equipment for an iron ore pelletizing plant designed to produce 3.85-million m.t./yr of pellets. The plant is scheduled to be commissioned in mid 2012.

Pöyry awarded biomass boiler engineering project in U.S.

April 7, 2010 — We Energies (Milwaukee, Wisc.; www.we-energies.com) has awarded Pöyry Oyj (Helsinki, Finland; www.poyry.com) an engineering contract for a €185-million capital project for a new 50-MW biomass cogeneration plant to be constructed at the Domtar paper mill facility in Rothschild, Wisc. The value of Pöyry's assignment is estimated at approximately €6.5 million. Construction for the new facility is planned to start in the spring of 2011 with the biomass cogeneration facility starting operation in late 2013.

SGL and BMW plan a new carbon fiber plant in the U.S.

April 6, 2010 — SGL Group SE (Wiesbaden, Germany; www.sglcarbon.com) and BMW Group (Munich, Germany; www.bmwgroup. com) have announced that their joint venture, SGL Automotive Carbon Fibers LLC, will build a state-of-the-art carbon fiber manufacturing plant in Moses Lake, Wash. During the initial phase, $100 million will be invested. The fibers manufactured at Moses Lake will be used exclusively for BMW Group's upcoming Megacity Vehicle. This new vehicle is set to be launched before 2015.

SABIC signs an agreement with Celanese for the construction of a polyacetal facility

April 1, 2010 — SABIC (Riyadh, Saudi Arabia; www.sabic.com) has concluded an agreement with the Celanese Corp. for the construction of a 50,000 ton polyacetal (POM) production facility at the SABIC affiliate, National Methanol Co. complex in Jubail Industrial City, Saudi Arabia. The engineering and construction of the facility is expected to begin by 2011. The facility is planned to go onstream by 2013. Total invested capital in the project is expected to be around $400 million.

Bayer MaterialScience to build industrial-scale facility for eco-friendly chlorine

March 30, 2010 — Bayer MaterialScience (Leverkusen, Germany; www.bayermaterialscience.com) has signed a contract with plant engineering company Uhde to build a new plant for chlorine production based on common salt. The plant, which will have a capacity of 20,000 m.t./yr and be built at Chempark Krefeld-Uerdingen in Germany, is scheduled to start operating in the first half of 2011 (for more on the technology see p.16).

ABB wins order for new aluminum mill in China

March 25, 2010 — ABB (Zurich, Switzerland; www.abb.com) has won a $20-million order from Shandong Nanshan Aluminum to deliver electrical and automation solutions and engineering services for its new three-stand Tandem Cold Mill in Longkou, China. The new mill will have a capacity of 400,000 m.t./yr of aluminum coils that will be used to make aluminum cans and is scheduled to start operation in 2012.

MERGERS AND ACQUISITIONS

BTS and TU Dortmund establish new research company

April 19, 2010 — Bayer Technology Services (BTS; Leverkusen; www.bayertechnology.com) and the Technical University of Dortmund (both Germany; www.tu-dortmund.de) have established the Invite GmbH research company, which will operate a new research center at Chempark Leverkusen, Germany. Flexible and efficient production concepts that help to conserve resources will be developed and tested in this "factory of the future." The construction of the new building required is being funded in part by €5 million from the German state of North Rhine-Westphalia's Ministry of Innovation, Science, Research and Technology under Economic Stimulus Package II. Construction in the Cologne-Flittard section of the Chempark Leverkusen site is scheduled to begin in spring 2010, with completion expected one year later.

Evonik purchases colloidal silica maker in the U.S.

April 15, 2010 — Evonik Degussa Corp. (Parsippany, N.J.; www.evonik.com) has purchased a controlling interest in Harris & Ford Silco, LLC (Portland, Ore.), from Harris & Ford, LLC (Indianapolis, Ind.), for an undisclosed sum. The company has been renamed Evonik Silco Materials, LLC and will remain in Portland. Evonik Silco Materials manufactures colloidal silica and ultra-high purity silica, a key component of the chemical mechanical polishing (CMP) process in the semiconductor manufacturing industry. Financial details of the transaction were not disclosed.

Joint development of new organic semiconductors

April 13, 2010 — Merck KGaA (Darmstadt; www.merck.de) and Plastic Logic GmbH (Dresden, both Germany; www.plasticlogic.com) have announced plans to jointly develop, test and commercialize Merck's new organic semiconductors in Plastic Logic's displays. The production and launch of these new materials are planned for 2011.

Globe Specialty Metals acquires Core Metals Group

April 1, 2010 — Globe Specialty Metals, Inc. (New York; www.glbsm.com) has acquired Core Metals Group, LLC , one of North America's largest producers of high-purity ferrosilicon and other specialty steel ingredients. Globe paid $52 million in cash for the company, which was owned by the Ospraie Funds. The Core Metals Group, headquartered in Coraopolis, Pa., services the steel, chemical and other industrial markets. ∎

Dorothy Lozowski

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CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957-59 = 100)	Feb.'10 Prelim.	Jan.'10 Final	Feb.'09 Final
CE Index	539.1	532.9	532.3
Equipment	641.1	631.8	631.9
Heat exchangers & tanks	587.3	571.9	587.0
Process machinery	610.4	601.9	615.2
Pipe, valves & fittings	796.1	794.5	770.6
Process instruments	420.5	419.8	384.6
Pumps & compressors	903.4	903.0	897.0
Electrical equipment	468.4	469.2	458.7
Structural supports & misc	660.0	640.2	660.9
Construction labor	329.9	331.0	323.7
Buildings	500.3	494.8	495.5
Engineering & supervision	342.4	342.4	349.8

Annual Index:

2002 = 395.6
2003 = 402.0
2004 = 444.2
2005 = 468.2
2006 = 499.6
2007 = 525.4
2008 = 575.4
2009 = 521.9
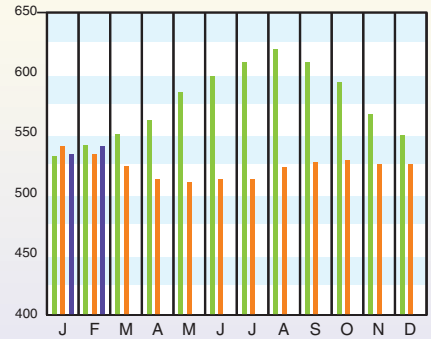
Starting with the April 2007 Final numbers, several of the data series for labor and compressors have been converted to accommodate series IDs that were discontinued by the U.S. Bureau of Labor Statistics


## CURRENT BUSINESS INDICATORS

|	LATEST		PREVIOUS				YEAR AGO	
CPI output index (2000 = 100)	Mar.'10 =	96.9	Feb.'10 =	96.2	Jan.'10 =	96.0	Mar.'09 =	90.0
CPI value of output, $ billions	Feb.'10 =	1,636.1	Jan.'10 =	1,636.9	Dec.'09 =	1,616.8	Feb.'09 =	1,431.4
CPI operating rate, %	Mar.'10 =	72.1	Feb.'10 =	71.5	Jan.'10 =	71.1	Mar.'09 =	65.5
Producer prices, industrial chemicals (1982 = 100)	Feb.'10 =	265.7	Jan.'10 =	260.1	Dec.'09 =	254.9	Feb.'09 =	224.1
Industrial Production in Manufacturing (2002=100) *	Mar.'10 =	100.5	Feb.'10 =	99.6	Jan.'10 =	99.4	Mar.'09 =	96.1
Hourly earnings index, chemical & allied products (1992 = 100)	Mar.'10 =	149.6	Feb.'10 =	150.1	Jan.'10 =	150.5	Mar.'09 =	145.7
Productivity index, chemicals & allied products (1992 = 100)	Mar.'10 =	137.4	Feb.'10 =	139.1	Jan.'10 =	134.4	Mar.'09 =	130.3

CPI OUTPUT INDEX (2000 = 100)
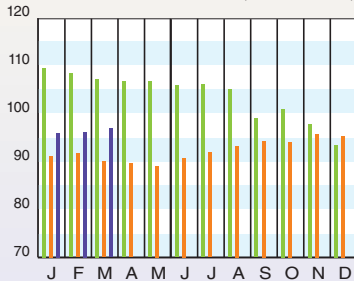
CPI OUTPUT VALUE ($ BILLIONS)
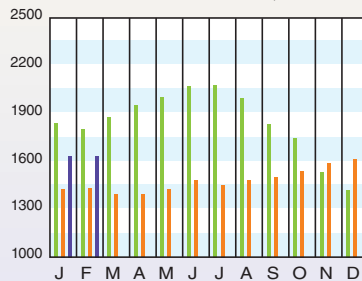
CPI OPERATING RATE (%)
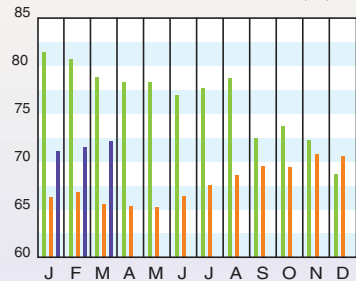
MARSHALL & SWIFT EQUIPMENT COST INDEX

(1926 = 100)	1st Q 2010	4th Q 2009	3rd Q 2009	2nd Q 2009	1st Q 2009
M & S INDEX	1,448.3	1,446.5	1,446.4	1,462.9	1,477.7
Process industries, average	1,510.3	1,511.9	1,515.1	1,534.2	1,553.2
Cement	1,508.1	1,508.2	1,509.7	1,532.5	1,551.1
Chemicals	1,481.8	1,483.1	1,485.8	1,504.8	1,523.8
Clay products	1,496.0	1,494.3	1,495.8	1,512.9	1,526.4
Glass	1,403.0	1,400.1	1,400.4	1,420.1	1,439.8
Paint	1,515.1	1,514.1	1,515.1	1,535.9	1,554.1
Paper	1,416.4	1,415.8	1,416.3	1,435.6	1,453.3
Petroleum products	1,615.6	1,617.6	1,625.2	1,643.5	1,663.6
Rubber	1,551.0	1,560.5	1,560.7	1,581.1	1,600.3
Related industries					
Electrical power	1,389.6	1,377.3	1,370.8	1,394.7	1,425.0
Mining, milling	1,552.1	1,548.1	1,547.6	1,562.9	1,573.0
Refrigeration	1,772.2	1,769.5	1,767.3	1,789.0	1,807.3
Steam power	1,475.0	1,470.8	1,471.4	1,490.8	1,509.3

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
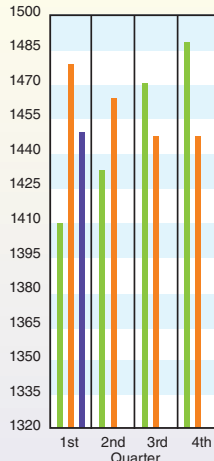
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CURRENT TRENDS

Global industrial production, as measured by the Organization for Economic Cooperation and Development (OECD)'s composite leading indicator (CLI), rose in February, and continues to point to economic expansion, the American Chemistry Council (ACC) says. Rates of expansion varied in different regions, with the strongest signs seen in Japan and the U.S.

Meanwhile, for the first time since January 2008, capital equipment prices (as reflected in the February 2010 CEPCI, above) have eclipsed those of the same period the previous year.

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