CHEMICAL ENGINEERING

July 2012

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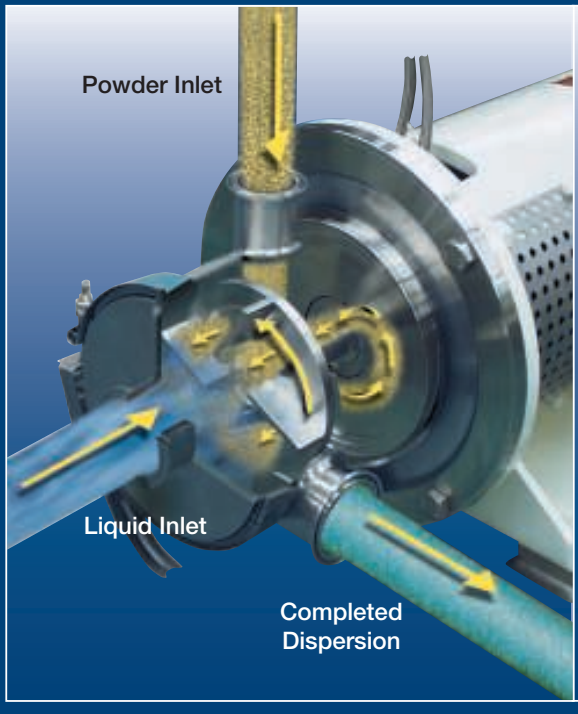

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BPA WORLDWIDE

Editor's Page

Finalists Announced for 2012 Personal Achievement Award

In nearly every issue of this magazine, a majority of the content focuses on the roles that technologies — and the companies that supply them — play in the chemical process industries (CPI). Indeed, products and services bond the CPI together, but the strength of that bond depends unequivocally on people. That is why once every-other year, we turn our focus inside out and recognize the accomplishments of individuals with our Awards for Personal Achievement in Chemical Engineering.

Early in a given award year, the Personal Achievement Award competition is announced in the magazine (see January, p. 15), and readers are invited to submit nominations. Nominees may be from anywhere in the world, and need not be chemical engineers by degree. The unyielding requirement is a record of notable achievement in the application of chemical engineering principles for solving industrial, community or governmental challenges.

The nomination period for the 2012 award has now closed, and the nominations have been screened for verification. Nomination packages for the following finalists have been sent to the board of judges, who will work over the summer to select the winners:

Steve Donen, vice president of process development & engineering, Rivertop Renewables
Mark W. Geeting, senior engineer, Savannah River Remediation, LLC
Arshad Chughtai, professor of chemical engineering, Institute of Chemical Engineering & Technology, University of the Punjab, Lahore, Pakistan
Manish Vrajlal Shah, lead process engineer, Ranhill WorleyParsons Sdn Bhd
Joao Gomes, professor, ISEL – Instituto Superior de Engenharia de Lisboa, Portugal
Rama Krushna Chary, environmental engineer, Kuwait Oil Co.
Rajeev Gautam, president and chief executive officer, UOP, a Honeywell Co.
Dominic C. Y. Foo, professor of process design and integration, University of Nottingham, Malaysia Campus
Fabio Bravo, process engineering technical manager, The Dow Chemical Co.
Glenn Eagle, research and development leader for structural bonding, North America, Dow Automotive Systems
Duraid Fadhil Ahmed, head of chemical engineering dept., University of Tikrit
Dianne Dorland, head of chemical engineering dept., Rowan University
Charles E. Easley, senior process engineer, BSI Engineering
Yan Liu, school of chemical engineering, Qinghai University
Glen J Bertini, president, Novinium, Inc.
M. O. Garg, director, CSIR-Indian Institute of Petroleum

The winners will be announced at an award ceremony to be held at ChemInnovations (November 13–15; New Orleans, La.; www.cpievent.com). Meanwhile, their accomplishments will be detailed in a News article to appear in *Chemical Engineering's* November or December issue. If you know one of these individuals, please congratulate him or her on being selected as a finalist. ■

Rebekkah Marshall

Letters

Call For Innovative Technologies

In addition to best practices and practical how-to presentations (see May, p. 6) ChemInnovations Conference & Expo (November 13–15, New Orleans, La.; www.cpievent.com) is looking for abstracts that describe new, novel and innovative technologies that help improve plant operations, efficiency and safety or reduce costs or risks in some other way.

These abstracts will be considered for inclusion in the Chementator Lightning Rounds. These quick-paced interviews are conducted by *Chemical Engineering* editors and take place on the exhibit hall stage during lunch and the hospitality hour.

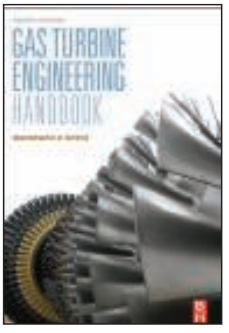
To submit an entry for consideration, please visit www.cpievent.com/call_for_technologies/. Be prepared to answer as many of the following questions in as much detail as you can (answering each question is not mandatory, but it helps increase the chance that your abstract will be accepted):

1. Who is the team responsible for this breakthrough technology? (Include names of people and companies that were vital to the development)
2. What is the technology you are announcing? Is it a new process? A new way to do something? A novel device that is unlike any other?
3. Please describe it fully. Is it patented? If so, what is the patent number? When was it patented?
4. What is the key characteristic (or characteristics) that make this technology unique and sensational? Does it have to do with a new application of an existing device or system? Is it, for instance, a device that can detect something to a greater extent than any other device (or system or process)?
5. What does this invention or development do? Where is it used? What was done before your device came along? Be specific.
6. How does this device system or process work to achieve these results? Include a description as if you were writing a laboratory procedure for a very conscientious student. If possible, include types of equipment, temperatures, and concentration limits achieved.
7. How does that compare with the existing technology for this application? And can you quantify these benefits over what has been done or is currently done?
8. How much does it cost? Is it economically viable? How so? (Prices are not necessarily important, but relative savings or other data that help compare it to established methods are helpful.)
9. What stage of development is it in? Is it commercial? If so, when and where will (or has it been) commercialized, and for whom? State the company if you can.
10. If it is not already commercial, when will it be? Are you looking for partners? How will it be offered commercially (for license or for sale)?

The deadline for entries is September 1, 2012. For questions about abstract submissions contact Cassie Davie, +1-713-343-1891, cassied@tradefairgroup.com.

Priority will be given to unique technologies that are being launched for the first time at ChemInnovations. ■

Bookshelf



Gas Turbine Engineering Handbook. 4th ed. By Meherwan P. Boyce. Elsevier Inc., 30 Corporate Drive, 4th floor, Burlington, MA. Web: elsevierdirect.com. 2011. 1,000 pages. $150.00.

Reviewed by Amin Almasi,
Rotating machine consultant
Brisbane, Australia

Gas turbines are cornerstones of modern industry and are widely used in the chemical process industries (CPI). New developments have increased the number of gas turbines in use and made them important prime movers, with efficiencies above 60% when used in a combined-cycle mode. Gas turbines are the most complex rotating machines in use today, and engineers challenged by their complexity will appreciate the in-depth knowledge and experience shared by Boyce, a widely recognized expert in the field of rotating machinery.

The 4th ed. of Boyce's book discusses advances in the areas of design, fabrication, installation, operation and maintenance of gas turbines. It is written to fully explain modern gas-turbine technology, as well as associated problems and solutions. The book provides excellent guidance for engineers who may specify, design, manufacture, manage, operate or maintain gas turbines.

The book's strength lies firmly in the modern information and data it contains, and the detailed explanations of practical issues and examples. Few of the many existing gas-turbine books reach the level of comprehensiveness and practicality that this book does. Following the suggestions presented will likely save time and money during gas turbine specifying, purchasing, commissioning and startup, and may even enhance the overall process efficiency.

In the 4th ed., chapters have been totally rewritten in the areas of combustors, and axial and radial turbine expanders. New sections on combustors deal with combustion problems, low-emission combustors and issues associated with these combustors, such as flashback problems. Throughout the boook, the author's numerous practical notes are particularly useful.

Editor's note: *For additonal comments from Almasi on this book, including a breakdown of section and chapter topics, as well as an expanded list of recently published books, see the online version of the bookshelf column in the Web extras box at* ***www.che.com****.*

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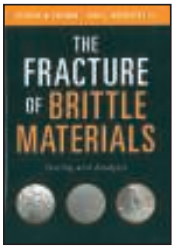
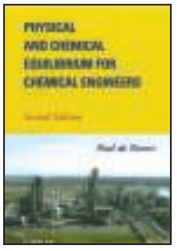
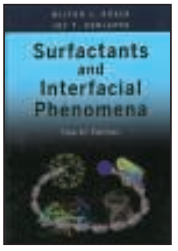
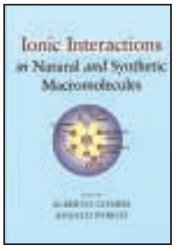
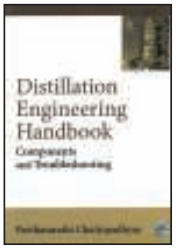










The Fracture of Brittle Materials: Testing and Analysis. By Stephen W. Freiman and John J. Mecholsky, Jr. John Wiley & Sons Inc., 111 River St., Hoboken, NJ 07030. Web: wiley.com. 2012. 182 pages. $125.00.

Physical and Chemical Equilibrium for Chemical Engineers. 2nd ed. By Noel de Nevers. John Wiley & Sons Inc., 111 River St., Hoboken, NJ 07030. Web: wiley.com. 2012. 357 pages. $130.00.

Distillation Engineering Handbook: Components and Troubleshooting. By Parthasarathi Chattopadhyay. Tata McGraw-Hill Education Pte. Ltd., 7 West Patel Nagar, New Delhi 110008. Web: tatamcgrawhill.com. 2012. 1,302 pages. $55.00.

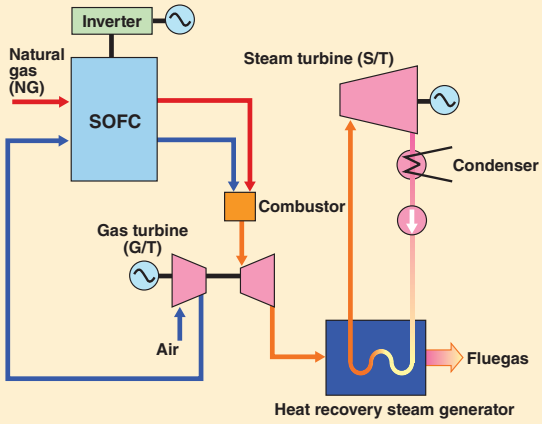
Surfactants and Interfacial Phenomena. 4th ed. By Milton J. Rosen and Joy T. Kunjappu, Jr. John Wiley & Sons Inc., 111 River St., Hoboken, NJ 07030. Web: wiley.com. 2012. 600 pages. $135.00.

Ionic Interactions in Natural and Synthetic Macromolecules. Edited by Albert Ciferri and Angelo Perico. John Wiley & Sons Inc., 111 River St., Hoboken, NJ 07030. Web: wiley.com. 2012. 852 pages. $175.00.

Turbulent Drag Reduction by Surfactant Additives. By Feng-Chen Li, Bo Yu, Jin-Jia Wei, Yasuo Kawaguchi. John Wiley & Sons Singapore Pte. Ltd., 1 Fusionopolis Walk #07-01 Solaris South Tower, Singapore 138628. Web: wiley.com. 2012. 256 pages. $195.00. ■

The quest for a more-efficient gas-fired power generator

Mitsubishi Heavy Industries, Ltd. (MHI; Tokyo, Japan; www.mhi.co.jp) will begin developing basic technologies for a triple combined-cycle power-generation system that integrates solid-oxide fuel cells (SOFC) and a gas turbine combined cycle (GTCC) power generation system. Under the umbrella of the New Energy and Industrial Technology Development Organization (NEDO), the company will launch a two-year study this year as part of a project entitled "Development of Systems and Basic Technologies for Solid Oxide Fuel Cells."



In a triple combined-cycle power-generation system, an SOFC power generator is placed before the GTCC system (flowsheet). By generating power at three stages — the fuel cell, gas turbine and steam turbine — the resulting fuel cell combined cycle (FCCC) system achieves outstanding efficiency in generating power from natural gas. The FCCC system is expected to achieve the world's highest power generation efficiency, exceeding 70% (lower heating value; LHV) for several-hundred-megawatt-class power generation, and over 60% (LHV) efficiency for several tens-of-megawatts-class power generation, says MHI.

As part of the study, MHI will develop the basic technologies needed to combine SOFC and gas-turbine power generation systems. For the SOFC system, the company will test the system's characteristic features and durability under high pressure (up to 3.0 MPa, gage). Issues to be considered for the gas turbine system include conversion of gas turbines and combustor development. MHI also plans to demonstrate a power generation simulation involving SOFC and a gas turbine system working in conjunction.

MHI sees FCCC triple combined-cycle power generation as a "revolutionary, epochal" technology that will result in 10 to 20% improvements in power generation efficiency over existing natural-gas-fired power generation systems. The company plans to pursue development based on the results of the basic technologies study, with the ultimate goal of commercializing the technology.

ADN production

Nylon-polymer producer Invista (Wichita, Kan.; www.invista.com) has developed new technology for the production of adiponitrile (ADN), a key ingredient for nylon 6,6. The advances, which came as a result of $40 million of R&D spending, can improve product yields, reduce energy consumption and enhance process stability compared to existing technologies, Invista says. The new ADN technology also virtually eliminates benzene from the production process. Invista has been operating its proprietary technology at pilot-scale for two years at its R&D facility in Orange, Tex. The company is pursuing plans to deploy the new ADN technology at its existing facilities.

NET Power

The Shaw Group Inc. (Baton Rouge, La. www.shawgrp.com) is teaming up with Net Power LLC (Durham, N.C.; www.netpowerllc.com) and Exelon to develop a new technology for gas-fired power generation. Called NET Power, the new technology is based on a high-pressure, supercritical CO_2 oxy-fuel power cycle, which is said to produce cost-effective power with little or no air emissions.

Shaw will acquire a substantial ownership position (up to 50%) in Net Power LLC, the developer of the technol-

(*Continues on p. 10*)

Making carboxylic acids from alkynes and CO_2

The research groups of professor Yasuyuki Tsuji and assistant professor Tetsuaki Fujihara at Kyoto University (Japan; www.ehcc.kyoto-u.ac.jp) have developed a copper-catalyzed reaction for synthesizing carboxylic acids, such as acrylic acid, using carbon dioxide as a raw material. The reaction involves the hydrocarboxylation of alkynes with CO_2 over a Cu catalyst. Two copper-based complexes showed high catalytic activity when using a hydrosilane as a reducing agent. The use of mild and easy-to-handle hydrosilane as a reducing agent realizes highly efficient hydrocarboxylation of alkynes to unsaturated carboxylic acids.

The chemists obtained the methyl ester of (E)-2,3-diphenyl-2-propenoic acid with 86% yield by the hydrocarboxylation of diphenylacetylene using $HSi(OEt)_3$ as a reducing agent in 1,4-dioxane, after reacting for 4 h at 100°C. The reaction mechanism is believed to occur in three steps: (1) the generation of the activated copper catalyst; (2) the formation of an intermediate compound with a copper-carbon bond; and (3) carbon-carbon bond formation by the reaction of CO_2 to produce the corresponding carboxylic acid.

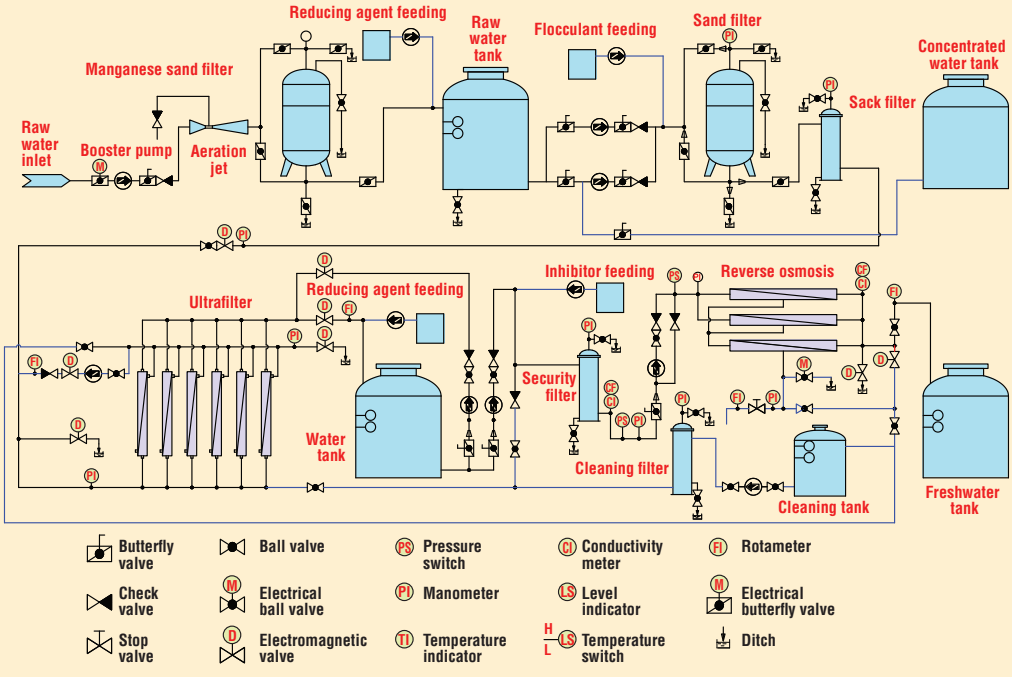
Industrially relevant acrylic acid is obtained when using acetylene as the alkyne. Also, the reaction of hydrosilane and symmetrical aromatic alkynes in toluene produced the corresponding α, β-unsaturated carboxylic acids with 60–90% yields, depending on the alkyne used, with E stereoselectivity.

The reaction is said to be less expensive than alternative routes, which require a palladium catalyst, and therefore may be a method for utilizing CO_2.

Note: For more information, circle the 3-digit number on p. 56, or use the website designation.

A treatment process for coal-bed-methane-extraction water

In the development process for coal-bed methane, water is produced from wells. It is high-salinity water, with total dissolved solids (TDS) generally at least 1,000 mg/L. The main concern with coal-bed methane co-produced water is the amount of Na^+ and its influence on the environment. Therefore, the water must be treated before discharge and cost-effective technologies are needed to allow the use of the water for irrigation, livestock watering and industrial uses. The technologies available include evaporation, ion exchange, electrodialysis and reverse osmosis (RO).



The first pilot-scale demonstration in China for treating and recycling coal-bed methane extraction water has been conducted by a team from the Graduate University of the Chinese Academy of Sciences (Beijing; www.gucas.ac.cn), led by professor Zhang Hongxun. The team focused on coal-bed-methane co-produced water in Liulin County of Luliang City, Shanxi Province, and developed a system with sand filtration, ultrafiltration (UF) and RO to treat that water.

In the process (flowsheet), the raw water is first aerated to increase the amount of dissolved oxygen. The water is then passed through a manganese sand filter, sand filter and bag filter to remove Fe, Mn and suspended solids. The water passes the UF system, and then goes through a security filter in the RO system. Finally, the output water from RO enters storage tanks.

The chemical components of coal-bed-methane co-produced water are mainly HCO_3^-, CO_3^{-2}, Cl^-, Ca^{+2}, Mg^{+2}, and Na^+. There are also small amounts of K^+, F^-, Hg, Cd, and Cr^{+6}. At Liulin, a single well produced up to 10 m^3/d of water in the early stage and reached 20 m^3/d for normal extraction. The chemical oxygen demand (COD) of the water was low, in the range of 0.5 to 3.6 mg/L, indicating a low level of organic pollution.

In the pretreatment process, the COD removal rate was 45.7%, TDS removal was 4.94%, Cl^- removal was 42.4% and NH_3–N removal was 46.2%. In the RO stage the total removal rates for COD, NH_3–N, Cl^- and TDS were 81.0, 85.4, 97.7 and 99.7%, respectively. The water quality met the "Drinking Water Standards" (GB 5749-2006).

Making artificial water channels

A group of scientists from Fudan University (Shanghai, China; www.fudan.ac.cn) China, has reported what it claims to be the first example of artificial single-molecular water channels that can transport water across lipid membranes.

Transmembrane water transport — through water channel proteins called aquaporins — is of crucial importance in living organisms because it regulates the osmotic pressure of cells. The development of synthetic systems with high water-transport capability could lead to new devices for medical use or environmental applications, such as water purification and desalination.

The creation of synthetic water transport systems has been difficult to achieve because of a lack of synthetic architectures that could form long and narrow channels for water.

The Fudan University group says it was inspired to design artificial water channels by mimicking the single pore feature of natural channel proteins. It constructed the water channels from single pillar[5]arene molecules with hydrazide-containing side channels.

A member of the group, professor Hou Jun-Li says the group attached 10 hydraz-

(*Continues on p. 12*)

(*Continued from p. 9*)

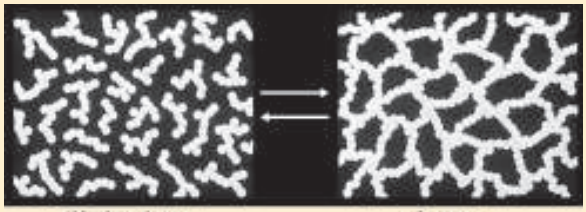
ogy, and will have exclusive worldwide rights to engineer, procure and construct NET Power plants. Shaw will invest up to $50.4 million as milestones are completed for the four phases of the project. Phases 1 and 2 (front end engineering and combustor rig testing) are expected to be completed in 2012. Phase 3 — construction of a 25-MW plant — is expected to be completed in mid-2014. Development of the first full-scale commercial natural-gas plant is expected to begin by early 2015.

This coated silica additive improves adhesive performance

A recently launched, polymer-coated, fumed silica additive improves the performance of structural adhesives — those designed to bear loads. The new additive is capable of reducing the adhesive's application viscosity, while simultaneously improving its ability to maintain a bead profile (sag resistance).

Known as Cab-O-Sil Ultrabond, the additive was developed by Cabot Corp. (Boston, Mass.; www.cabot-corp.com) for epoxy and polyurethane adhesives applications in the automotive, aerospace and other industries.

When added to an adhesive, the properties of the Cab-O-Sil allow it to self-assemble into three-dimensional networks (photo) that increase the effective viscosity of the adhesive and prevent it from sagging. With Cab-O-Sil added, the adhesive material behaves thixotropically, meaning its viscosity decreases as shear forces are applied.



As soon as a shear force is applied, such as in pumping or dispensing the material, the 3D networks break down and the adhesive flows more easily, explains Elizabeth Sims, global applications development lead for the Performance Segment of Cabot Corp. By carefully controlling the size and morphology of the silica particles, as well as the surface chemistry of the silicone-coated particles, the hydrophobic additive is tuned precisely to interact with the epoxy adhesive in a way that allows the self-formation of the 3D networks.

"It's a fine balance" among a number of parameters, Sims adds, to achieve the rapid viscosity recovery in the adhesive. The coated silica product makes up between 2 and 5 wt.% of the adhesive.

A step closer to replacing platinum in catalytic converters

The research group of Masaru Ogura, an associate professor at the Institute of Industrial Science, University of Tokyo (www.u-tokyo.ac.jp), has clarified the degradation mechanism and the role potassium carbonate plays in the catalyst systems used for reducing soot from the exhaust of diesel engines. Based on its studies, the group has proposed a new catalyst system with enhanced tolerance to catalyst degradation.

In 2008, Ogura and coworkers, in collaboration with Mitsubishi Motors Corp., discovered that the zeolite so-

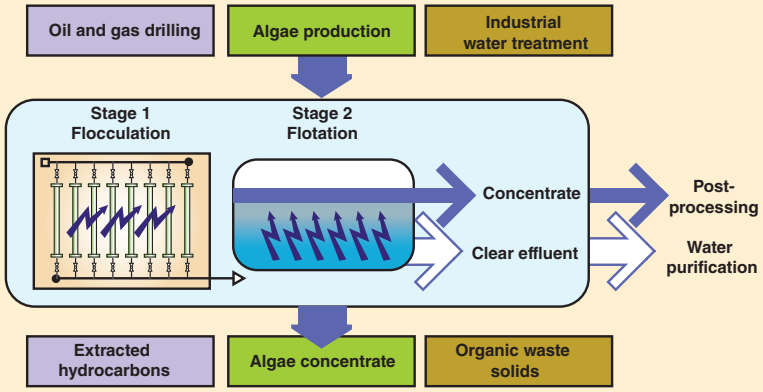
(*Continues on p. 12*)

Algae-harvesting technique applied to produced water

Technology originally developed for dewatering algae has shown success in separating hydrocarbons from produced water that results from oil and gas drilling. The method could be used in treating produced water for onsite re-use as hydraulic fracturing fluid.

To harvest oil from algae, OriginOil Inc. (Los Angeles, Calif.; www.originoil.com) developed an electroflocculation process in which precisely tuned electromagnetic waves are used to bring algae cells out of aqueous solution and rupture cell walls (see *Chem. Eng.*, June 2009, p. 12). The same technology has now been used to break oil-water emulsions in samples of produced water from oil wells in West Texas. Third-party testing has shown that the technology removed 98% of hydrocarbons in the produced water sample in a single pass.

Produced water from oil and natural gas wells comes out of the ground with significant levels of suspended hydrocarbons in it, explains OriginOil CEO Riggs Eckelberry. "We believe our proprietary process is the most efficient method available today for separating oil from produced water," he adds.



OriginOil recently filed two patents for its methods of solute extraction from aqueous media using a modular device. Eckelberry says the company intends to pursue licensing agreements for its technology in the oil and natural gas industries, while still working toward using the technology to harvest bio-oil from algae.

Stabilizing wine

The E.U. recently opened the door to additional applications for Velcorin in the wine industry. As a result, this Lanxess AG (Leverkusen, Germany; www.lanxess.com) technology can now be deployed at all stages of wine production and for all wines. Velcorin (dimethyldicarbonate, DMDC) can be used to optimize existing processes, such as filtration or the addition of sulfites, and also as a replacement for hot filling and preservation with sorbates.

Matthias Bracke, senior product manager of the Beverage Technology business line in Lanxess' Material Protection Products business unit, says "stabilizing wine with Velcorin has no negative influence whatsoever on the taste, odor or color. ... It does not alter the character of the wine in the slightest, it simply helps to stabilize it."

In wine production, Velcorin protects the wine from microbiological attack through undesired microorganisms, and thus protects it from spoilage. Especially with high-quality wines, which are stored in barrique barrels for many months and even years, there is a large risk of attack by *Brettanomyces*, a genus of yeast that gets into the wine and frequently only becomes noticeable in the taste after several months. Velcorin is said to be highly effective against such yeasts.

Replacing Platinum in Catalytic Converters

(*Continued from p. 11*)

dalite ($Na_4Al_3(SiO_4)_3$), in combination with K_2CO_3 could be used for reducing soot emissions. But this K_2CO_3/sodalite system lost its catalytic activity after long-term driving tests due to the separation of potassium carbonate from sodalite. Ogura analytically clarified that the separation of potassium carbonate was caused by the metallization of potassium and the vaporization of potassium through oxidation.

Now, Ogura has discovered that K_2CO_3 supported on Na-type nepheline (K_2CO_3/Na-nepheline) has enhanced tolerance against water washing after heat treatment at 800°C. This system maintains its catalytic function on the purification of soot in diesel exhaust emissions after water washing of the catalyst system.

Today, platinum-based catalysts are widely used in catalytic converters for diesel engines for reducing soot, hydrocarbons, oxides of nitrogen (NOx) and carbon monoxide. Although the K_2CO_3-based catalyst only reduce soot emissions, Ogura believes it could replace up to one half of the Pt requirements in catalytic converters.

Making Artificial Water Channels

(*Continued from p. 10*)

ide-incorporated side chains to the central pillar[5]arene scaffold. The hydrazide units in the side chains were expected to form cylinders through intermolecular hydrogen bonding to induce the molecules to produce tubular structures, he says. Inserting the molecules into the lipid membranes of vesicles leads to the transport of water through the channels produced by single molecules.

The channels exhibited transport activity at a very low channel-to-lipid ratio (0.027 mol%), and achieved a water permeability of 8.6×10^{-10} cm/s.

Also, as with natural water-channel proteins, the artificial systems also blocked the transport of protons. The researchers controlled the transport by controlling the NaCl concentration inside the vesicles. The osmotic pressure difference prevents water inside the vesicles from coming back out.

Testing of a new oil-sands-recovery process

A consortium of companies — Laricina Energy Ltd., Nexen Inc., Suncor Energy Inc. and Harris Corp. — has completed its initial-phase testing of the Enhanced Solvent Extraction Incorporating Electromagnetic Heating (ESEIEH) project at Suncor's Steepbank mine facility north of Fort McMurray, Alberta, Canada. The $33-million program is supported by the Climate and Emissions Management Corp., and the test was approved by the Energy Resources Conservation Board.

The proof-of-concept tests confirm the ability to generate, propagate and distribute electromagnetic heat in an oil-sands formation. It also validates the analytical tools and methods used to predict the performance of the process, which will now move forward to a field pilot next year.

ESEIEH replaces the need for water (which is used in conventional steam-assisted gravity drainage methods) by applying Harris' patent-pending antenna technology to initially heat the oil sands with radio waves. An oil solvent is then injected to dilute and mobilize the bitumen, so that it can be extracted and transported for further processing.

Biodegradable PBS

Uhde Inventa-Fischer AG (Domat/Ems, Switzerland and Berlin, Germany; www.uhde-inventa-fischer.com) has expanded its product range to include polybutylene succinate (PBS) technology. The PBS biopolymer is produced from succinic acid and butanediol in a continuous polycondensation process using the company's proprietary two-reactor process, which includes the two reactors, Espree and Discage, and enables high-quality granulate to be produced in an energy efficient and resource-conserving manner, says the company. Plants with a capacity of at least 40,000 metric tons per year of PBS are offered.

PBS has properties comparable to those of polypropylene and polyethylene, making it suitable for packaging materials, films textiles and more. ❐

A compact thermal storage system

There's a growing trend toward generating electricity from biogas (see pp. 15–17), but roughly half of the total energy content of the fuel is released as heat, which is dissipated into the atmosphere unused. To improve the overall efficiency, researchers from the Fraunhofer Institute for Interfacial Engineering and Biotechnology (IGB; Stuttgart; www.igb.fraunhofer.de) and ZeoSys GmbH (Berlin, both Germany) are developing a new thermal-storage system that can store 3–4 times the amount of heat as water, and can even operate at temperatures exceeding 100°C. The system uses zeolite pellets that capture or release heat, depending on the demand. A 750-L test facility is being tested. ■

FDA reform bill passes U.S. Congress

In late May, both the U.S. Senate and House passed the U.S. Food and Drug Administration (FDA) Reform Act of 2012 (H.R. 5651). The legislation is aimed at better protecting the nation's drug supply.

H.R. 5651 includes authorization of the Generic Drug User Fee Action (GDUFA), legislation that would improve the drug supply chain by requiring inspection of all foreign and domestic drug production facilities. Under the terms of GDUFA, the generic drug industry would pay approximately $1.5 billion over five years in return for faster and more predictable review of generic drug applications, which should help reduce drug shortages and bring drugs to market faster. The legislation would allow the FDA to perform inspections on a risk basis, focusing on the facilities posing the greatest risk to drug safety.

Sandia opens cybersecurity research center

Sandia National Laboratory (Albuquerque, N.M.; www.sandia.gov) has just opened its new Cybersecurity Technologies Research Laboratory (CTRL) at the Sandia facility in Livermore, Calif.

"With CTRL, we can run experiments and talk more freely about a wide range of cyber research activities, and we can do so with a variety of U.S. and international collaborators but without some of the unrelated restrictions that are often associated with a national laboratory," says Jim Costa, senior manager of computational sciences and analysis at Sandia's California site.

"At the same time, we can do these things in a uniquely controlled environment, where we know what activities are taking place and we can monitor who and what else is in the building," he adds.

Specifically, CTRL aims to do the following: develop the science and computing foundation necessary for robust cyber security R&D; develop relationships to help understand the full range of technical threat concerns facing industry, government (nonclassified) and academia; develop, test and help implement cybersecurity approaches in real-world situations; promote disciplines that support the advancement of cybersecurity; and develop political and social awareness of the real, imminent threat and the consequences posed by cyber exploits and attacks.

EPA BIODIESEL NUMBERS

The U.S. Environmental Protection Agency (EPA; Washington, D.C.; www.epa.gov) says that 94.5 million gallons of biodiesel were produced in April, reporting year-to-date production of 331 million gallons through the end of April. Biodiesel production is reported under the EPA's biomass-based diesel category in the Renewable Fuel Standard (RFS).

Last year, the biodiesel industry set a new production record of nearly 1.1 billion gallons, supporting more than 39,000 jobs across the country. Made from an increasingly diverse mix of resources, such as recycled cooking oil, soybean oil and animal fats, biodiesel is the first and only EPA-designated advanced biofuel that is produced on a commercial scale in the U.S. It can be used in existing diesel engines without modification. To view the latest figures, visit www.epa.gov/otaq/fuels/rfsdata/2012.emts.htm.

Plant-based PET collaborative formed

The Coca-Cola Co., Ford Motor Co., H.J. Heinz Co., Nike Inc. and Procter & Gamble recently announced the formation of the Plant PET Technology Collaborative (PTC), a strategic working group focused on accelerating the development and use of 100% plant-based PET (polyethylene terephthalate) materials and fiber in their products.

The new collaborative was formed to support new technologies in an effort to move from the current material, which is partially made from plants, to material made entirely from plants. PTC members are committed to researching and developing commercial solutions for plant-based PET plastic, and will aim to drive the establishment of common methodologies and standards for the use of plant-based plastic, including life cycle analyses and universal terminology.

PET is a durable, lightweight plastic used by PTC member companies in a variety of products and materials, including bottles, apparel, footwear and automotive fabric and carpet.

The collaborative builds upon the success of Coca-Cola's PlantBottle packaging technology, which is partially made from plants and has demonstrated a lower environmental impact when compared to traditional PET plastic bottles.

EPA promotes safer nonylphenol ethoxylate alternatives

Through its Design for the Environment (DfE) Alternatives Assessment Plan, the EPA has released a final alternatives assessment report identifying eight safer alternatives to nonylphenol ethoxylates (NPEs), which are widely used in industry as surfactants and wetting agents for detergents, cleaners, carriers and other commercial uses. When released into the environment, NPEs and NPE derivatives can degrade slowly and be highly toxic to aquatic animals.

The report provides information on the availability of safer alternatives, as well as the DfE's hazard evaluation method for surfactants and progress to date toward adopting safer surfactants.

Using hazard-based criteria, EPA evaluated hundreds of chemicals for biodegradability and potential effects to aquatic organisms.

DfE's Alternatives Assessment Program is intended to help industry choose safer chemicals and offers a basis for informed decision-making by providing a detailed comparison of the potential human and environmental effects of chemical alternatives. To date, the DfE program has labeled more than 2,700 safer products, including detergents that contain only safer surfactants and other chemicals. ■

Scott Jenkins

THE BIOGAS BOOM

New technologies are increasing production efficiencies, making this renewable energy source even more popular

It probably isn't going to solve all the world's energy needs, but producing biogas from waste can help slash the energy bills at some production plants, sewage-treatment plants and even farms. And for those companies offering biogas technology, business is booming.

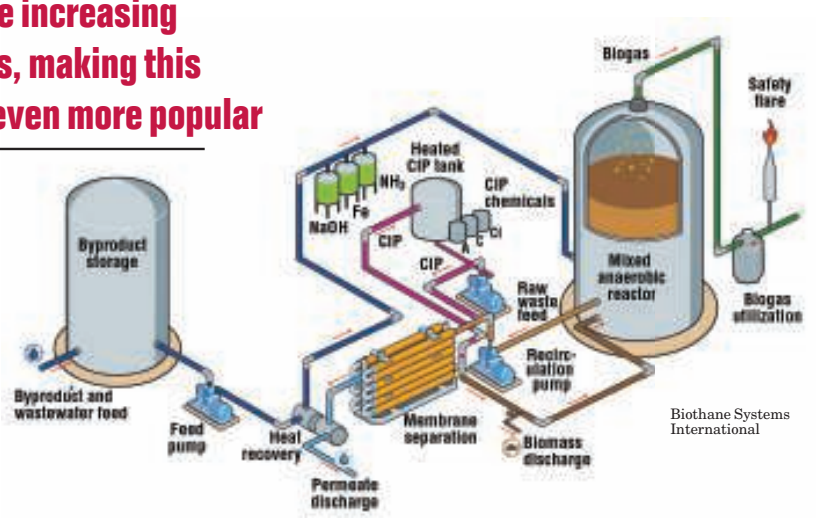
For example, Eisenmann Anlagenbau AG & Co. KG (Böblingen, Germany; www.eisenmann.com) has been active in the biogas market since 2003, and the company says that international demand has grown considerably in recent years. More than 90 plants of very different designs of Eisenmann are currently in operation, including 20 biogas plants in Italy.

Germany is the undisputed biogas champion, with over 7,100 of the estimated 10,000 biogas plants in Europe. These facilities account for 11% of the electricity generated in Germany by renewables, according to BioPro Baden-Württemberg GmbH (Stuttgart, Germany; www.bio-pro.de).

The U.S. has over 2,200 sites producing biogas, according to the American Biogas Council (Washington, D.C.; www.americanbiogascouncil.org), including 186 anaerobic digesters on farms, 1,500 at wastewater treatment plants and 576 landfill-gas projects.

Anaerobic digestion

Most of the thousands of operating biogas plants are using conventional digestion systems, which are basically large towers or tanks designed to process dry compost or wet sewage sludge and industrial wastewater by anaerobic fermentation. In these warm, sealed airless containers, bacteria metabolize organic matter into biogas, a mixture of carbon dioxide, methane and small amounts of other gases (H_2O, H_2S and NH_3). Depending on the feedstock, the methane content will vary from 30–40 vol.% (for sewage sludge and manure) to as much as 80 vol.% (fats and oils). The biogas can be used — sometimes directly — as a fuel for heating, burned in a gas engine to generate electricity and heat (in combined heat and power (CHP) systems), compressed for operating vehicles, or cleaned up for injection into natural-gas pipelines.



Biothane Systems International

FIGURE 1. The Memthane process features an anaerobic membrane bioreactor, which increases the biogas yield in a much smaller footprint compared to conventional anaerobic digesters

In Spain, for example, Sener Ingeniería y Sistemas, S.A. (Madrid, Spain; www.sener.es) developed its Valpuren process specifically for treating pig manure. This waste is normally used as a fertilizer, but in some rural areas, the livestock density is so large that the amount of manure is too much for this disposal option — the nitrogen levels in ground water can exceed E.U. Directives.

The Valpuren process uses an anaerobic mesophillic (30–35°C) biodigestion of the manure to make biogas, which is used for cogeneration of heat and electricity, as well as a fertilizer in a form that can be stored (dry pellets). Biogas yields are increased by co-digestion with other waste feeds, such as those from food processors or slaughterhouses. Since the process was commercialized in 2001, five industrial plants are now processing 100,000 ton/yr of pig manure and generating 16 MW of CHP.

Eisenmann recently designed a new composter with a biogas plant to convert an existing biomass-composting plant of the Swedish waste-utility Västblekinge Miljö AB (Mörrum, Sweden), enabling the company to convert 20,000 ton/yr of regional biowaste into 1,500 tons of fuel. When the facility starts up later this year, it will feature two horizontal plug-flow digesters, each with a capacity of 800 m^3. These digesters are made of precast, reinforced concrete and equipped with special horizontal agitators. Operating at temperatures of 55°C (thermophillic), the system almost completely digests the feedstock within 25–30 days, while destroying potentially harmful pathogens in the process, says Eisenmann.

Another biogas plant featuring thermophillic fermentation — one of the largest in Europe — has been designed

and built by Farmatic Anlagenbau GmbH (Nortorf, Germany; www.farmatic.com) as a general contractor for Göteborg Energie AG. First feedstock was supplied to the new biogas plant in Skövede, Sweden earlier this year. The plant processes mainly slaughterhouse waste along with other industrial food waste at a temperature of 52°C, and can produce up to 800 m^3/h of biogas, which can then be upgraded to 500 m^3/h of biomethane. This biomethane will be used for fuel in cars and public transportation.

Anaerobic MBRs

While demand for conventional digestion systems continues to grow, anaerobic analogs of proven membrane bioreactor (MBR) technology have now been developed, which enables the processing of wastewater with very high levels of COD (chemical oxygen demand), but requires significantly less space, says Jan Pereboom, marketing manager at Biothane Systems International (Delft, The Netherlands; www.biothane.com) — a subsidiary of Veolia Water Solutions and Technologies. In the past, the option for treating industrial wastewater with COD levels of 20,000–250,000 ppm has been limited to energy-intensive combined anaerobic and aerobic treatment systems, or paying high external disposal costs.

Now, a new option is available: Biothane's Memthane process, which opens the door to treating high-strength, high-solids wastes found in distilleries, dairies (whey), bioethanol plants and coffee producers. Memthane (Figure 1) combines two proven technologies: Biothane's anaerobic biological wastewater treatment and the ultra-filtration (UF) membrane separation technology of Pentair X-Flow B.V. (Enschede, The Netherlands; www.x-flow.com). Influent is fed to the anaerobic bioreactor where the organic components are converted into energy-rich biogas. Next, the anaerobic effluent is processed through the UF membrane unit, separating the "clean" permeate from the biomass. The biomass is returned to the bioreactor, while the ultra-clean filtrate is discharged as particle-free, low BOD (biochemical oxygen demand) and COD effluent, often at levels low enough for direct discharge to the sewer. If required, several polishing techniques, both physical and biological, are available to further treat the suspended free effluent and recover nutrients, for instance by struvite precipitation.

FIGURE 2. Biogas yields can be increased by up to 15% by adding BioCrack electrokinetic disintegration modules

Incorporating the UF step into the digestion means all the bacteria are returned to the reactor, along with undigested biomass. As a result, a Memthane system achieves a higher conversion — 98–99% of the COD converted to biogas compared to 85–95% in a conventional digester, says Pereboom. This higher conversion means the size of the plant can be one half to a third that of a conventional digester treating the same waste stream, he says.

Depending on the waste stream, the biogas produced can cover 40–60% of the production plant's electricity and heat demand — and even 100% in distilleries, for example. Investment costs of a green-field Memthane system are equal to or lower than conventional technologies, while the overall operating costs are much lower for energy, chemicals and sludge disposal, says Pereboom. "The soda costs for pH correction in the reactor are much lower in the Memthane systems."

The first industrial-scale demonstration plant has been operating for four years at a dairy in the U.S. Since the Memthane technology was commercialized last year, the first four units are now under construction, and over 14 pilot plants have been built. The largest plant under construction is a 20,000 m^3 reactor (for treating bioethanol condensate), which can generate around 6 MW of electricity.

Eisenmann is also developing an anaerobic MBR, which features a rotating membrane disk filter developed in cooperation with the Fraunhofer Institute for Interfacial Engineering and Biotechnology (IGB; Stuttgart, Germany; www.igb.fraunhofer.de). Thanks to the Eisenmann ceramic filter, the high concentrated sludge is centrifuged from the membrane by rotation, which results in a high flux compared to other anaerobic MBRs, says the company. The technology has been pilot tested since 2009 in a 10-m^3/d unit in Knittlingen, Germany, and plans are underway to treat up to 35 m^3/d.

Boosting efficiency

Another way to boost the efficiency of biogas plants is the BioCrack electrokinetic disintegraton technology (Figure 2), which was introduced by Hugo Vogelsang Machinenbau GmbH (Essen/Oldb., Germany; www.vogelsang-gmbh.com). Before entering the digester, slurries flow through the BioCrack module and are exposed to a high-voltage field generated by internal electrodes. The field breaks up agglomerations (aggregates and colloids) of dead bacteria and organic matter, thereby increasing the availability of the nutrients for the fermenting bacteria. By improving the utilization of substrates, gas yields are increased by up to 15%, says the company.

BioCrack also reduces floating and sinking layers, as well as viscosity in

Evonik Industries AG

FIGURE 3. Modules of these spaghetti-like hollow-fiber membranes can upgrade biogas to a CH_4 purity of 99%

the digester. This decreases the mixing and pumping requirements, thus reducing energy consumption by up to 30%, says Vogelsang.

Since the technology was introduced in 2009, more than 23 modules have been installed.

Last May, Lanxess AG (Leverkusen, Germany; www.lanxess.com) introduced Bayoxide E 16 — a highly effective synthetic iron oxide for reducing H_2S in biogas — that can be added directly to the fermenter. Bayoxide E 16 reacts directly with H_2S to form iron sulfide and sulfur, which together with the fermentation residue, can be used to fertilize fields. Because of the additive's nearly 100% purity, it removes nearly all of the H_2S (typically around 500 mg/m^3, depending on the waste being fermented). As a result, a metering system is not required and the cost of secondary biogas desulfurization by activated carbon absorption is "significantly" reduced, says the company. Removing the H_2S directly inside the fermenter also helps avoid damage from corrosion caused by the formation of sulfuric acid, adds Lanxess.

An approach to reduce the amount of experimental work needed to optimize biogas yields has been demonstrated by AICOS Technologies AG (Basel, Switzerland; www.aicos.com) and Flensburg University of Applied Sciences (Flensburg, Germany). The method, called Statistical Design of Experiments (DoE) uses a mathematical approach to systematically tune various parameters, such as enzyme concentration, milling time, temperature, pH and so on, and predict gas yield, before actually doing experiments, says Philippe Solot, CEO at AICOS. The method, which uses Stavex software from AICOS, makes it possible to perform only the required experiments, in a structured way instead of having to "play the lottery of trial and error," says Solot.

Membrane separation

Although conventional gas-sweetening technologies can be and are used to upgrade biogas for injection into natural gas pipelines, the added expense for chemicals and handling makes this option uneconomical for some smaller biogas plants. To reduce the costs and complexities, membrane separation is being developed as an option for both new and existing biogas plants.

For example, MainSite GmbH & Co. KG (Obernburg, Germany; www.mainsite-service.de) has entered the biogas-purification market, and now offers membrane-based purification plants under the brand MainMethan. The plants combine the company's experience in manufacturing of fiber-spinning plants — including those for membrane fibers — and in chemical plant construction to deliver optimized, economical methane-extraction plants.

In MainMethan plants, CO_2 is separated from the biogas using a special polymer membrane. The final product gas, with more than 97% biomethane, meets the requirements for input to the natural gas network. Unlike alternative separation methods, membrane purification requires no chemical additives or expendables. Low operating costs and maintenance are another advantage of MainMethan, because it requires only one compressor, says the company.

Last year, Evonik Industries AG (Essen, Germany; www.evonik.com) commercialized hollow-fiber membrane technology, tradenamed Sepuran Green, for upgrading biogas to biomethane. The membranes, which look like spaghetti (Figure 3), are based on high-performance polymers (polyimides) that have been used in the past for hot-gas filtration, and optimized for the selective separation of CO_2 (as well as H_2O and traces of H_2S and NH_3) and from CH_4. At pressures of up to 25 bars, methane of 99% purity or more can be achieved, says Evonik.

Pilot trials of the new membrane modules have been underway since 2011 at an existing biogas plant in Neukirchen an der Vöckla, Austria. Since then, several larger pilot and first production-scale units will go onstream in the course of this year. Evonik has also invested "upper single-digit" million euros in a new fiber-spinning plant for producing Sepuran fibers at its Schörfling, Austria site. Startup of the large-scale plant is planned for Q4 2012.

Eisenmann, too, has developed a new biogas-upgrading system based on Evonik's selective membrane technology. "This highly flexible modular process is ideal for low-capacity upgrading," says Lukas Graf, a biogas-upgrading specialist at Eisenmann. "The throughput rate can be easily adapted to the [user's] specific requirements, and our equipment can be retrofitted to any biogas plant, not just those built by Eisenmann." The upgrade becomes an increasingly attractive, economical option for plants that produce less than 500 Nm^3/h of raw biogas.

The first unit has already been sold to an existing customer, and this summer will process up to 210 Nm^3/h of biogas — equivalent to the annual natural gas consumption of 430 four-person households or 800 LNG-powered vehicles driving 13,000 km/yr. ■

Gerald Ondrey

DEVELOPMENT SPEEDS UP IN CATALYSIS

Dow Chemical

Consista C601 catalyst, a 6th generation, non-phthalate-based technology offers resin manufacturers the ability to produce more differentiated, higher performance resins with broader applicability, while helping to produce lighter, faster, cleaner and clearer resins

R&D headway is helping traditional processes keep pace and newer ones get into the race

BASF Catalysts

BASF offers a portfolio of catalysts and adsorbents that cover a range of oleochemical processing needs. In addition to existing products, research and development continues to design new technologies for these markets

There might be as many categories of catalysts as there are chemical processing applications. And, no matter what the specialty or application, most catalyst producers are in a constant state of research and development in order to meet the demands of their chemical processing customers, as well as to develop innovative catalysts for new applications and growing market areas. Recent efforts of some of the top catalyst producers are improving resin properties, helping narrow the economic disadvantage of oil-based polymers and speeding up new possibilities in biorenewables and microchannel reactors.

Polyolefin catalysts

Resin manufacturers are always look for resins that are lighter, cleaner, faster and clearer, says Cheri Wrenn, global product market manager with The Dow Chemical Co. (Midland, Mich.). "Lighter resins are desirable because they allow down gauging, which means manufacturers can use less resin to obtain the same strength and stiffness characteristics of packages that traditionally used more resin. This saves resin and reduces transportation costs because the load is lighter," she says.

Technologies that improve the resin processing speed are also in demand, for their potential to eliminate bottlenecks in the process or simply move product through the machinery quicker. Cleaner resins are also desirable because they reduce VOC (volatile organic compound) emissions, lower catalyst residue and improve taste and odor for food and beverage packaging applications. And, clearer resins are always in demand for product packaging applications.

In response to these trends, Dow recently introduced Consista C601 catalyst. This sixth generation, non-phthalate-based technology offers the ability to produce more differentiated, higher performance resins with broader applicability, while helping to produce lighter, faster, cleaner and clearer resins. Consista C601 catalyst, along with Consista donors, improves reactor operability and on-stream time, according to Wrenn. It is also compatible with Dow's SHAC catalysts, allowing for simplified transitions to this new generation of catalyst.

"When we talk about polyolefins, resin manufacturers want a catalyst that can make a broad range of resin products," says Wrenn. "They want a catalyst with broad flexibility in that it can make a variety of different types of resins and make them well. And, Consista C601 has that ability."

Wrenn says Consista C601 customers can use one type of catalyst to produce different products without switching out catalysts. "Dow is developing catalyst donors for Consista that allow resin manufacturers to tweak the characteristics they are looking for in their product by using different donors, which is more straightforward than switching out catalysts for each product," she says. "The donors can help the catalyst make a broader range of resin products."

In addition, Consista C601 is applicable for use in all types of gas phase processes. "That's a desirable trait for resin manufacturers, as well, if they are operating multiple technologies, because you can have one catalyst that works in all of them," notes Wrenn.

Chemical catalysts

For chemical processors in a variety of sectors, fast innovation time is critical because the market environment and process requirements change quickly. For example, low cost shale gas is currently flooding the U.S. market, boosting all processes that are based

BASF Catalysts

Catalysts that help producers save investment cost and energy consumption are also in demand. For example in the production of styrene, BASF's S6-42, a highly active new catalyst, enables producers to increase productivity while simultaneously reducing energy consumption

FOR MORE INFORMATION

BASF Catalysts	www.catalysts.basf.com
The Dow Chemical Co.	www.dow.com
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on natural gas (NG). Ethane as a by-product of NG production is becoming abundant, driving production of low-cost ethylene. On the other hand, Naphtha cracking is becoming less competitive, leading to significant deficits in its downstream products, propylene and higher olefins. This trend, in turn, is driving investments in dedicated technologies to produce naptha-based olefins.

As a result, BASF Catalysts (Iselin, N.J.) is working closely with technology providers to develop innovative catalytic processes for the production of propylene. "While natural gas-based processes are booming, oil-based processes are disadvantaged," says Dr. Hans-Peter Neumann, senior vice president with Process Catalysts and Technologies, BASF. "Higher feedstock costs require smart and flexible solutions to stay competitive."

As an example, phthalic anhydride (PA) is an important component of plasticizers. It is primarily produced from *o*-xylene. Costs for *o*-xylene have risen dramatically, as it is based on crude oil. As a result, high *o*-xylene prices are threatening the profitability of PA producers who suffer from lower demand and over capacity.

So, says Neumann, BASF Catalysts is helping its customers tackle this challenge with two different solutions. First, by developing O4-88 as a new product, which produces the same amount of PA from significantly less *o*-xylene. Second, by developing a series of catalysts that allow producers of PA to replace expensive *o*-xylene with less expensive naphthalene. "These new catalysts achieve a higher yield than previous generations and help to reduce raw material costs," he says. "Both solutions will significantly improve process economics and profitability."

Another noteworthy trend is the development of catalysts that help producers save investment cost and energy use. One prominent example, says Neumann, is the production of styrene, where S6-42 is BASF's latest catalyst generation. This highly active new catalyst enables producers to increase productivity while simultaneously reducing energy consumption.

Developed markets also require more sustainable solutions that can reduce the carbon footprint, using bio-based raw materials and unwanted byproducts. New processes with minimized contamination of air and water are another development trend, says Neumann. Many processes are currently developed for these applications, which are also driven by new environmental regulations.

BASF developed a process for the conversion of bio-based glycerin to propane diol, which is an important raw material for engineering plastics (polyurethanes). The first reference plant was successfully started up in 2011, and there is strong market interest in developing further capacity, says Neumann.

Boosting bio-renewables

In general, says Erwin Teirlinck, business development manager, chemical catalysts, with Johnson Matthey (West Deptford, N.J.), catalyst users are interested in four main characteristics, including selectivity, activity, mechanical strength and lifetime.

There is a growing need for highly selective catalysts. Even a one percent increase in selectivity could result in less byproduct formation, saving significant costs in end product purification. Potentially, a more selective catalyst leads to a more sustainable process due to less waste generation.

The use of more active catalysts results in less catalyst consumption per ton of manufactured product. Active catalysts often allow lowering process temperature, while maintaining conversion, which results in overall energy cost reductions.

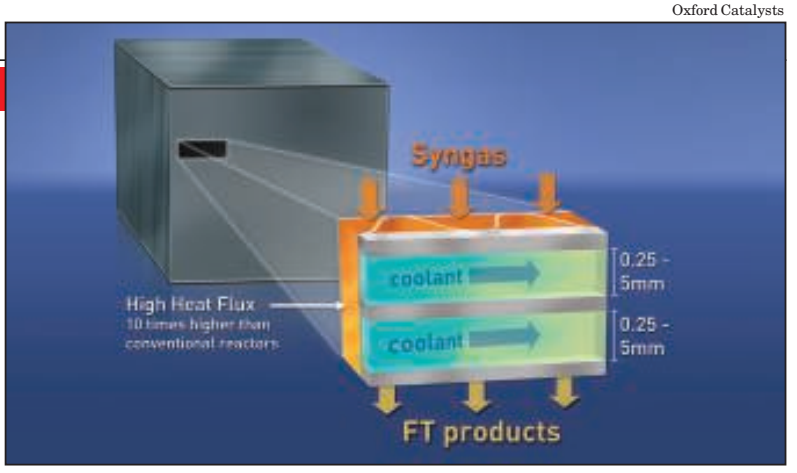
Whether the catalyst is used in a powder form (such as slurry phase and fluidized bed reactors) or as particulates like tablets or extrudates (in fixed bed reactors), mechanical stability is a key characteristic when it comes to catalyst selection. A strong, mechanically stable catalyst retains its selectivity and activity for a longer period of time and causes fewer issues downstream in the process. And usually, lifetime or yield, expressed as tons of manufactured product per ton of catalyst, is key for the economic viability of the catalyst and is high on the agenda of catalysts users.

"In line with these overall trends in the chemical industry is the emergence of clean technologies and the use of bio building blocks, which is resulting in a growing interest in environmentally friendly catalysts and novel catalysts for the manufacture of bio-renewable chemicals," says Teirlinck.

For instance, Johnson Matthey is developing an innovative supported precious-metal catalyst, together with Jacobs Engineering, to replace undesirable mercury-based catalyst for making vinyl chloride monomer (VCM). The company has also initiated a research project to develop chromium-free catalyst formulations, primarily aimed at the production of fatty alcohols.

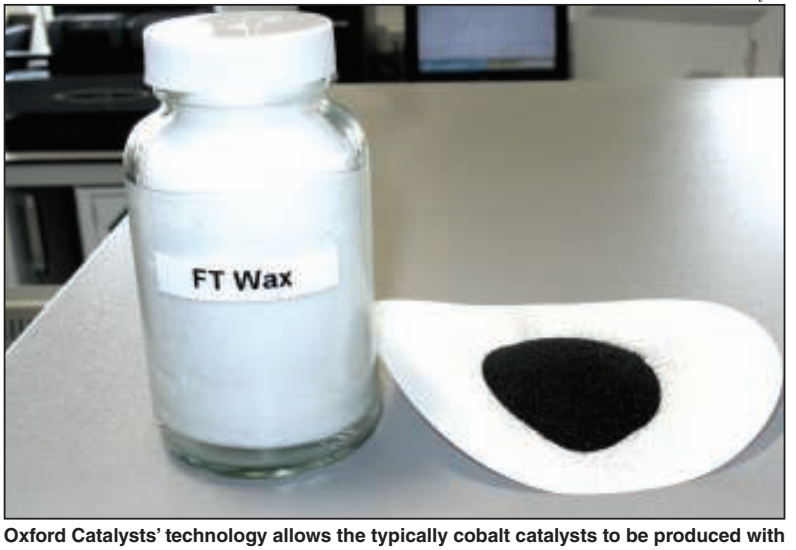
"Chemicals from bio-renewables is a new and fast growing application for catalysis," says Teirlinck. "We are working together with a number of companies in this area to jointly develop catalyst formulations and scale-up catalyst manufacture with the ultimate goal to commercialize these catalysts for large-scale production."

Oxford Catalysts



Microchannel Fischer-Tropsch reactors exhibit conversion efficiencies in the range of 70% per pass, and are designed for economical production on a small scale

Oxford Catalysts



Oxford Catalysts' technology allows the typically cobalt catalysts to be produced with a reduced need for precious metal promoters, without any loss of performance and with superior activity, selectivity and stability to conventional catalysts

Microchannel reactors

Microchannel reactors are compact reactors that have channels with diameters in the millimeter range. These small channels dissipate heat more quickly than conventional reactors with larger channel diameters, so more active catalysts can be used. Mass- and heat-transfer limitations reduce the efficiency of the large conventional reactors used for Fischer-Tropsch (F-T) and steam methane reforming (SMR) reactions and hydroprocessing. So, the use of microchannel processing makes it possible to greatly intensify chemical reactions, enabling them to occur at rates 10 to 1,000 times faster than in conventional systems.

Microchannel Fischer-Tropsch reactors, developed by Velocys (Plain City, Ohio) and using a new, highly active F-T catalyst developed by Oxford Catalysts (Oxfordshire, U.K.) are now available for the small-scale distributed production of fuels. These reactors exhibit conversion efficiencies in the range of 70% per pass, and are designed for economical production on a small scale. A single microchannel-reactor block produces some 30 barrels of synthetic fuels per day. In contrast, conventional FT plants are designed to work at minimum capacities of 30,000 barrels per day or higher.

Because microchannel reactors have the potential to unlock the distributed product of fuels and other materials on a small, decentralized scale, Oxford Catalysts has been working to develop catalysts for these applications, says Kai Jorosch, manager of catalyst and material sciences with Oxford Catalysts. "We've developed a series of catalyst platform technologies for the production of superactive catalysts for use in microchannel reactors," he says.

Among them is the organic matrix combustion (OMX) method, which makes it possible to produce catalysts with higher metal loadings, while still maintaining optimal crystalline sizes. Compared to conventional catalyst-production methods, such as incipient wetness impregnation, OMX produces more active and stable catalysts.

Catalysts for FT reactions are also being developed. In the FT process, a syngas consisting of a mixture of carbon monoxide and hydrogen is converted into hydrocarbons over a catalyst. Oxford Catalysts' technology allows the typically cobalt catalysts to be produced with a reduced need for precious metal promoters, without any loss of performance and with superior activity, selectivity and stability to conventional catalysts, notes Jorosch. It is now possible to use feedstocks such as natural gas and biogas, as well as coal, for the production of synthetic fuels.

SMR is another area of development for Oxford Catalysts. In SMR, methane gas is mixed with steam and passed over a catalyst to produce a syngas consisting of hydrogen and carbon monoxide. The reaction is highly endothermic, so it requires the input of heat. This can be generated by the combustion of excess methane and hydrogen produced. In microchannel SMR reactors, the heat-generating combustion and steam methane reforming processes take place in adjacent channels.

Overcoming heat and mass transfer limitations allows near-equilibrium conversion and selectivity at millisecond contact times. The high heat transfer properties of the microchannels and the close integration between combustion and reforming channels make this process very efficient. The microchannel SMR exhibits high mechanical strength, low pressure drop and excellent safety as no premixing between fuel and air is required. In the same way as superactive FT catalysts can unlock the potential of microchannels FT, the same applies with a superactive SMR catalyst. ■

Joy LePree

High-purity Processing

Watson-Marlow Tubing,

Meissner Filtration Products

Aquionics

Kason

This bioprocessing tubing is weldable

PureWeld XL tubing (photo) is a weldable tube for the biopharmaceutical and pharmaceutical industries, and is designed for high-purity and secure peristaltic pumping. A high-quality tube capable of completely secure welding, PureWeld XL allows for connector-free fluid paths to be assembled in minutes. PureWeld XL was developed in the company's extrusion facility, and tested using its peristaltic pumps. The test results show that PureWeld allows for the least internal spallation when compared to other weldable tubing. It allows the tube to remain pristine and outlast other brands, making it more economical than alternative products. PureWeld XL is a thermoplastic elastomer tubing and contains no animal-derived components that could leach into duty fluids. The product is ideal for use in sanitary environments from research to production, including cell media and fermentation, sterile filling and dispensing, high-purity water transfer, vaccine production, fluid transfer and filtration. PureWeld XL meets full bio-pharmaceutical testing standards including FDA (U.S. Food and Drug Administration) requirements and USP (U.S. Pharmacopiea) Class VI certification. — *Watson-Marlow Tubing, Wilmington, Mass.*

www.watson-marlow.com

This water disinfection system uses UV LEDs for efficiency

The UV-Pearl (photo) uses ultraviolet (UV) light-emitting diodes (LEDs) for water disinfection. The product offers highly efficient water disinfection for the pharmaceutical and healthcare industries. The UV-Pearl is easily integrated into OEM (original equipment manufacturer) devices, ultrapure-water-generation systems, process water loops, laboratory research equipment and washing machines. The unit's mercury-free design is for flows lower than 5 gal/min. The UV-Pearl's compact design allows for a large number of possible configurations. — *Aquionics, Erlanger, Ky.*

www.aquionics.com

A sanitary sifter with a low-profile

The model K30-1FT-SS ultra-sanitary sifter (photo) has an extra-low profile that reduces overall height by using two unbalanced-weight gyratory motors mounted on opposing exterior sidewalls of the unit, rather than a single motor positioned beneath the screening chamber. Using this company's Vibroscreen Flo-Thru design, the sifter passes on-size particles rapidly through a 30-in.-dia. screen. The screener is available in diameters from 18 to 84 in. All material-contact surfaces, as well as the floor stand are constructed of stainless steel with continuous welds polished to cGMP, USDA (U.S. Dept. of Agriculture) and FDA standards. — *Kason Corp., Millburn, N.J.*

www.kason.com

Make single-handed, aseptic fluid transfers with this system

The FlexCessory stand (photo) is used to secure this company's FlexFill single-use fluid transfer assemblies during use. Designed to optimize user convenience, the FlexCessory stand and FlexFill allow one-handed liquid transfers. The compact design of the assembly means users can set it up inside a laminar-flow hood for aseptic fluid transfers. Sterile bottled liquids can be conveniently transferred to

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

FlexFill for enhanced flexibility and security when adding fluids to either single- or multiuse bioreactors, the company says. Excess fluid can be stored in the assembly for future dispensing. The FlexCessory can accommodate all FlexFill biocontainer sizes from 500 mL to 6 L. — *Meissner Filtration Products, Inc., Camarillo, Calif.*
www.meissner.com

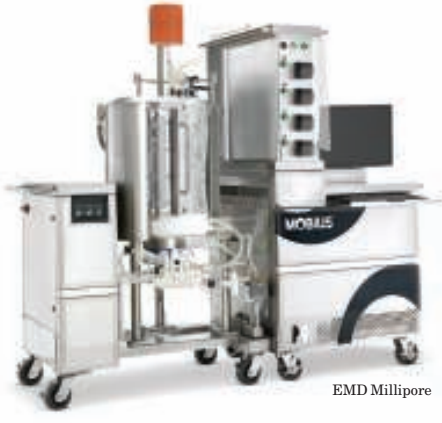
Colder Products

Value Plastics

Pepperl+Fuchs

A single-use bioreactor for cell culture

The Mobius CellReady 50-L bioreactor (photo) is a single-use, stirred-tank bioreactor designed for process development and pilot-scale mammalian cell culture. The bioreactor has a number of features that make it easier to use, more reliable and more flexible than existing single-use systems, the company says. The 50-L reactor size is the latest introduction to this company's single-use processing portfolio that spans cell culture to ultrafiltration of product. It is also part of a series of single-use bioreactors that have sizes from 3 to 200 L. — *EMD Millipore, Billerica, Mass.*
www.millipore.com



EMD Millipore

This coupling system provides sterile tubing connections

The AseptiQuik system (photo) is a line of connectors that allow users to quickly and easily make sterile couplings between two single-use systems, even in non-sterile environments. AseptiQuik connectors are available in 1/8-in. and 1/4-in. sizes for small-flow applications, as well as 3/4- and 1-in. connections for higher-flow applications. Other products in the line can integrate the company's Steam-Thru steam-in-place connector for cases where single-use processing systems need to be used with stainless-steel systems. — *Colder Products Co., St. Paul, Minn.*
www.colder.com

Single-use clamps that are ergonomic

PharmaLok clamps (photo) are sanitary clamps for securing fittings to bag ports and filters in the biopharmaceutical market. The clamps are ergonomically designed for one-handed operation, and do not require tools for attachment or detachment. The clamps provide an audible series of three clicks to confirm that a secure connection has been made. The PharmaLok hygienic clamps are made of a glass-filled nylon material that is certified for both USP Class VI and ISO 11137. — *Value Plastics, Fort Collins, Colo.*
www.valueplastics.com

These workstations are designed for cleanrooms

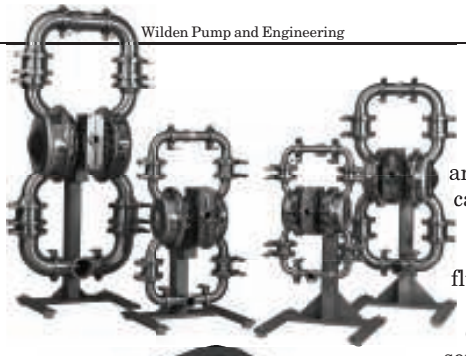
Aseptic Operator Workstations (photo) are specially designed for work inside cleanrooms. They are designed with a flush 316L stainless-steel faceplate, an ergonomically angled, aseptic keyboard with pointing options, and an industrial-grade monitor with an FDA-grade silicone gasket. The easy-to-use workstation can be used for a host of process control and other projects in sterile pharmaceutical environments. The units are suitable for use in general purpose areas, as well as Class 1, Div. 2 classified areas. The workstations are designed for easy installation in less than 30 min, with a caulk-free design, and spring-loaded wall clamps to anchor the housing. — *Pepperl+Fuchs, Twinsburg, Ohio*
www.pepperl-fuchs.us

Avoid contamination with seamless storage drums

This company's stainless-steel drums have a crevice-free interior for maximum protection against entrapment of residual materials. The seamless drums are designed for storing or transporting high-purity products. The sanitary, food-grade drums are manufactured with heavy-gauge T-304 stainless steel and have a 55-gal capacity. The drum also has a number of design options, such as a closed-head version for corrosive liquid applications, and an open-head drum with a removable cover for complete emptying and thorough cleaning of solids and viscous liquids. — *Skolnik Industries, Inc., Chicago, Ill.*
www.skolnik.com

Use these hygienic pumps to move pharmaceutical fluids

The Saniflo Hygienic Series is a range of air-operated double-diaphragm (AODD) pumps (photo, p. 57) for pumping process fluids in the pharmaceutical industry. The products in the series feature a number of elastomer options, such as full-stroke PTFE



Wilden Pump and Engineering

CraneChemPharma Flow Solutions

(polytetrafluouroethylene) integral piston diaphragms that offer superior product containment for highly aggressive fluids. Saniflo pumps are available with specialized air distribution systems, such as this company's Pro-Flo X Air Distribution System, which offers an efficiency management system to maximize operational flexibility. The Saniflo HS pumps are available in sizes from 1 to 3 in. and are constructed from stainless steel. — *Wilden Pump and Engineering Co., Grand Terrace, Calif.*
www.wildenpump.com

Get reliable high-temperature performance with this diaphragm

The EX Endurance Diaphragm (photo) is designed for life science applications that require reliable high-temperature performance for extended periods of time. Key features of the diaphragm's design include its extended life for longterm steam service, and a reduced requirement to re-tighten fasteners after installation. The EX Endurance Diaphragm can be used in steam distribution applications, as well as sterile barrier and block-and-bleed applications. — *CraneChemPharma Flow Solutions, Cincinnati, Ohio*
www.cranechempharma.com

Maintain sterility when disconnecting tubing

The Kleenpak Sterile Disconnector is the first device designed to maintain sterile integrity, even in cramped and uncontrolled environments, before and after separation of tubing. Its patented locking mechanism eliminates the risks associated with clamping and cutting, and requires no tools, calibration or maintenance. Disconnection is performed in less than 30 s, and sterility of the separate fluid paths is maintained throughout. The single-use Kleenpak facilitates secure fluid transfer, preserves product integrity, improves operator safety, and reduces product waste at all process stages of biopharmaceutical manufacturing, the company says. Originally introduced in 1/2-in. diameter, the Kleenpak sterile disconnector is now also available in 3/8- and 1/4-in. sizes. — *Pall Corp., Port Washington, N.Y.*
www.pall.com ■

Scott Jenkins

CHEMICAL ENGINEERING
FACTS AT YOUR FINGERTIPS
Department Editor: Scott Jenkins

Automated Weigh-Batching Systems

Automated systems for batch weighing can improve overall product quality by raising the accuracy and consistency of the mixture compared to what can be achieved with the manual addition of pre-weighed bags. Automated batch-weighing systems integrate load cells with connections, valves, relay hardware and process control software. These systems control one or more pieces of feed equipment that deliver different ingredients to a common receiving vessel at user-defined quantities. To take advantage of the benefits offered by automatd batch-weighing systems, consider the following items, some of which can also be applied to the selection of other weighing instruments.

Two approaches

When using a manual batch-weighing approach, a common practice may be to work with pre-weighed bulk bags, which can introduce error through incomplete manual emptying of the bag, or by having bag contents that are not exactly the weight stated. In addition to increasing accuracy, automated weigh-batching systems can simplify the addition of bulk product ingredients to blenders or other process vessels, as well as increase plant productivity.

In general, two automated weigh-batch methods exist: gain-in-weight systems and loss-of-weight systems.

Gain-in-weight. In this arrangement, batch ingredients are typically conveyed in sequence into a hopper above the process vessel or blender. The hopper is set on load cells that transmit weight-gain data to a programmable logic controller (PLC) that starts the conveyor for each ingredient and then stops it when the preset weight for that ingredient is reached. Gain-in-weight systems are generally preferable for weighing a larger number of smaller-volume ingredients. Costs can be minimized because only a single set of load cells is required for the entire gain-in-weight system.

Loss-of-weight. In this type of system, the source of each ingredient, such as a bulk-bag unloader, is mounted on load cells that transmit weight loss data to a controller that starts and stops each conveyor or rotary airlock valve to weigh each ingredient. As a conveyor unloads the material, load cells transmit loss-of-weight information to the controller. In general, loss-of-weight systems are more suitable for weighing a smaller number of larger-volume ingredients.

In many cases, the most suitable system depends on how and where the bulk material is received and stored. If the material is delivered by railcar or bulk truck, for example, loss-of-weight systems would be impractical because the material containers could not be mounted on the load cells required for that type of system. Conversely, if the material arrives in groups of bulk bags, loss-of-weight may be the most appropriate approach.

Loss-of-weight batch-weighing systems have the advantage of increased batch speed, if two or more ingredients are being added to a process vessel. For loss-of-weight systems, all ingredients can be weighed and discharged simultaneously, as opposed to sequentially, as is required in a gain-in-weight system.

Key parameters

In gain-in-weight systems, an important parameter that must be addressed is how to account for material that is still on its way to the scale after the batch controller has deactivated the material-feed device. The material-in-flight variable can be minimized by proper control sequencing and equipment positioning. If the discharge of the material conveyor is immediately above the gain-in-weight hopper, little in-flight material will result. In such an arrangement, the amount of in-flight material will tend to be relatively constant from batch to batch, so it can be compensated for by having the weigh-batch controller stop the feed device at a point prior to the hopper achieving the desired weight. In this way, the in-flight material fills in the difference and the desired weight is reached.

When load cells are located at floor level, they are more susceptible to damage and more likely to require frequent calibration after impacts with mobile plant equipment, such as pallet jacks or forklifts. In situations where the weigh hopper is suspended above the floor, the possibility can be virtually eliminated.

Load cells

As a weighing device for automated batch-weighing, load cells should be used for weighing ingredients over 10 kg up to several metric tons. When selecting a weighing system, always make an effort to stay in the mid-range of the unit's specified capacity with the loads that will be weighed typically. Heavy-range load cells cannot weigh small volumes of batch ingredients with high accuracy.

The moving parts of a load cell are constantly under stress, which can cause the accuracy of the cell to drift. Regularly scheduled calibration is needed to ensure consistently accurate results.

Calibration gauges the response of a load cell in an attempt to prevent out-of-specification results in a manufacturing process. Typically, calibrating a load cell involves using certified test weights to generate readings on the cell. If the cell readings do not match the test weights, manual or automatic adjustments can be made to correct the drift. Operators can perform the task for routine accuracy checks, but certification can be awarded only if a trained and certified technician performs the task with certified and traceable test weights.

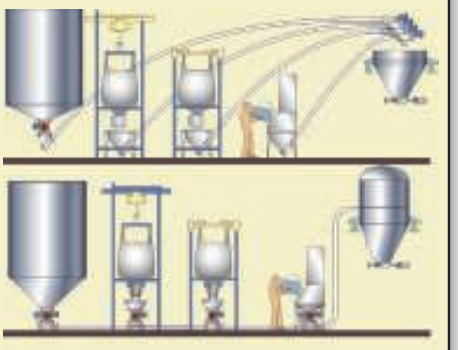


FIGURE 1. Mechanical (above) and pneumatic (below) gain-in-weight batching systems can transport material from silos, manual dumping stations, process equipment, bulk bags or any other source to a hopper, a blender, or other downstream equipment mounted on load cells

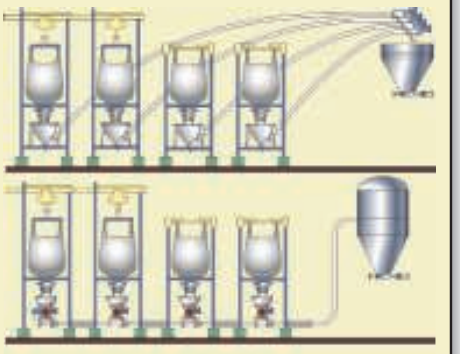


FIGURE 2. Mechanical (above) and pneumatic (below) loss-of-weight batching systems transport material from one or more bulk bags to a common hopper, blender, conveyor, shipping container, or any process vessel

Accuracy

No defined specification exists for accuracy in the weighing industry. Accuracy can be considered a combination of several different factors, including four quantifiable specifications: resolution, reproducibility, linearity and uncertainty of measurement.

Resolution. Resolution refers to the smallest change in mass that can be read on a particular scale (regardless of capacity).

Reproducibility. Reproducibility is the weighing device's ability to perform consistently over time and with multiple different operators. Reproducibility is often expressed as a standard deviation.

Linearity. Linearity represents the measurement of the weighing system's variance in accuracy over the weight values within its capacity range.

Uncertainty of measurement. The uncertainty of measurement refers to the difference between the measured weight of a given sample when compared to the true weight, with variances attributed to weighing environment and other factors. A common value for uncertainty of measurement is not to exceed 0.1% of the sample quantity.

Editor's note: This edition of "Facts at Your Fingertips" was adapted from the following articles: 1) Boger, D., Automating Your Weigh Batching System, *Chem. Eng.*, June 2008, pp. 75–79; and 2) Titmas, R. and Carey, S., Weighing Your Options: The 10 Most Important Scale Considerations, *Chem. Eng.* December 2007, pp. 61–65.

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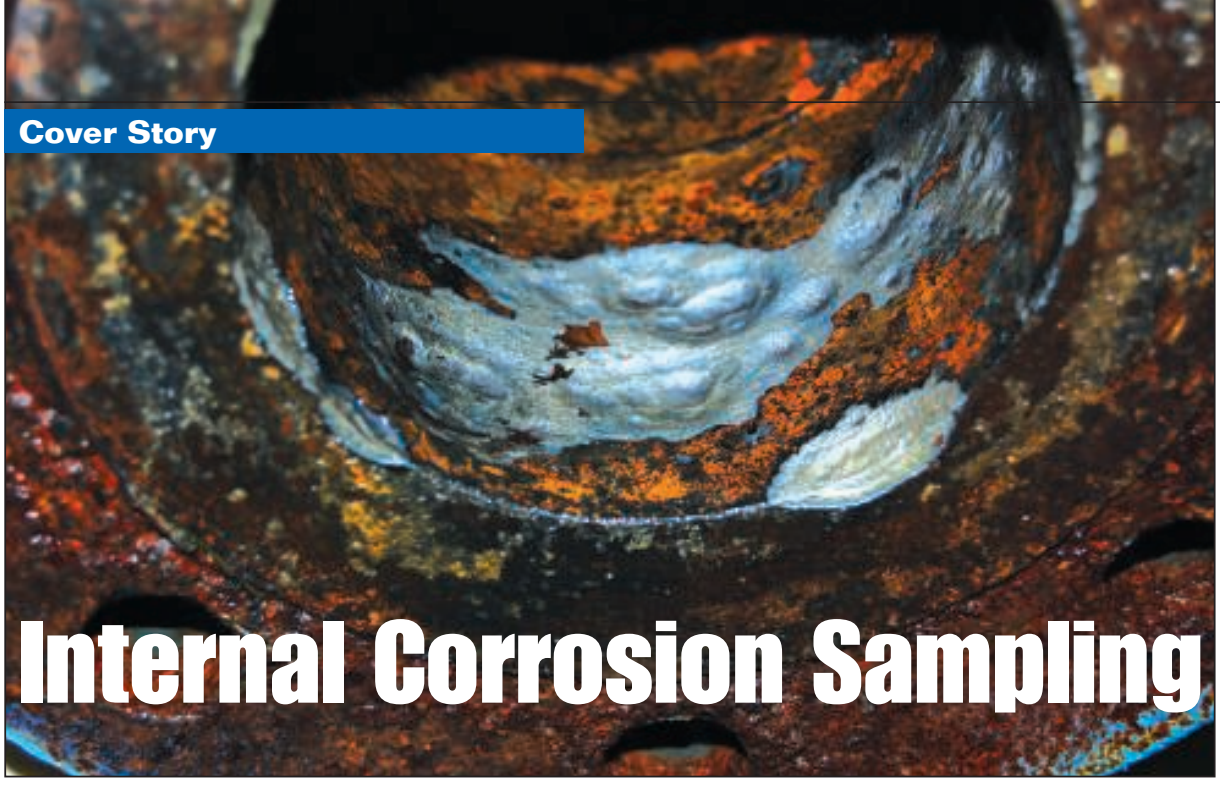

Internal Corrosion Sampling

Proper sampling and handling procedures are critical for supporting corrosion-management decision making

FIGURE 1. Data must be gathered from a number of different sources to formulate a complete picture of the internal environment of an asset or system

Jason Rine
MSES Consultants Inc.

Corrosion is a large and complex issue that is critical to the chemical process industries (CPI) as well as other industry sectors. Corrosion not only affects personal property like cars and homes but also affects commercial assets such as storage tanks, buildings, bridges, process equipment, and all types of piping. While corrosion is seen every day in our personal and professional lives, we rarely pause to understand the cause of the corrosion and, more importantly, how to mitigate it.

The most visible type of corrosion is generically called external corrosion. External corrosion has a range of causes from atmospheric corrosion to corrosion from stress corrosion cracking (SCC). Factors that cause external corrosion and the resulting problems that many engineers deal with everyday are generally well understood.

As an industry sector, the cathodic protection industry has developed an extensive range of design, testing and mitigation methods to help alleviate external corrosion. However, despite the expertise available to deal with corrosion, it costs the U.S. economy approximately $276 billion annually [*1*]. Included within this cost estimate are the effects of damage to infrastructure caused by internal corrosion.

Internal corrosion

Many misunderstandings about internal corrosion persist, and in some cases, internal corrosion is dismissed as fiction and overlooked until problems occur (Figure 1). Although internal corrosion has been recognized and dealt with for many years, understanding of the problem and the science behind it continue to evolve.

Before internal corrosion can be effectively mitigated or controlled, the asset or system in question has to be evaluated correctly. This is where proper sampling procedures come into play. Data must be gathered from several sources to help formulate a complete picture of the internal environment of the asset or system.

Some of the data necessary to properly evaluate an asset or system include: material type, system contents, operating conditions, and, most importantly, analytical data. To obtain valid analytical data, proper sampling and handling techniques must be employed.

Sampling methods

Internal corrosion sampling consists of several overlapping evaluation methods, some of which are performed with the asset or system operating normally, while other methods are performed with the equipment being operated specifically to facilitate the testing method. The most widely used methods for evaluating internal corrosion are the following:

- Bacterial analysis
- Coupons and probes
- Deposit analysis
- Gas samples
- Liquid samples
- Inline inspections

These sampling methods can be used independently, or in combination, to determine the extent and suspected causes of internal corrosion. This information can then be used to determine whether mitigating methods are necessary, as well as which sampling

FIGURE 2. (above) In field-sampling, some parameters must be analyzed onsite because of their time-dependency

FIGURE 3. (right) The type of material being tested dictates what time-sensitive testing needs to be performed onsite, and in what order

methods will be effective for determining whether or not the mitigation measures were successful.

Although there are generally many different assets and systems that are affected by internal corrosion, the sampling techniques used for gas and liquid pipelines can be adapted to work with virtually any other piece of equipment to obtain high-quality analytical data.

With the recent natural gas boom in several parts of the U.S., there is an increasing number of pipelines in place, and more are proposed for future installation. All of these pipelines could be affected by internal corrosion. With this resurgence of natural gas, along with the high-profile pipeline incidents that have occurred over the last few years, the need to understand and deal with any potential internal corrosion issues has never been greater. The situation makes proper sampling programs essential to any corrosion-management plan.

Sampling programs

When developing a sampling program, it is important to understand how the specific system has been operated, because the understanding can provide insight into the best areas from which to collect samples and install coupons and probes.

While developing the internal sampling program, it is necessary to have a basic understanding of the common potential causes of internal corrosion. These include acid gases (CO_2, H_2S), bacterial corrosion, erosion corrosion and combination corrosion. Once the potential threat or threats have been determined, the potential monitoring methods must be assessed to determine which ones would be the most useful for the involved system. For example, if acid gases are to be measured, gas sampling and analysis is always a good choice. If there is liquid flowing in the system, then liquid sampling is a good complement to the gas sampling to determine the levels of dissolved gases in the liquid (Figures 2 and 3). Conversely, if the system does not contain flowing liquids, the use of coupons and probes would be a good secondary choice.

No matter what type of sampling is to be performed, there are several general guidelines that should be followed to ensure that the samples are collected properly. These guidelines include the following:

- Use company standard operating procedures (SOPs) and proper safety standards
- Ensure that sampling kits are correct, and not expired, for the sample type being collected
- Review and understand all sampling instructions and procedures prior to field sampling
- Confirm that any equipment being used for sampling (including valves, piping and other associated equipment) is clean, to prevent instances of cross-contamination
- Ensure that the sample containers being used are clean, "first-use" containers
- Perform all field analyses as soon as possible
- In cases where a pipeline needs to be cut open, the pipe should be mechanically cut to preserve the integrity of the internal environment. Torch-cutting dries fluids, kills bacteria, accelerates chemical reactions, and has the potential to change any solid material

When performing field sampling, there are parameters that need to be analyzed onsite because of their time dependency. The material being tested dictates what time-sensitive testing needs to be performed onsite, and in what order.

Liquids

For liquids, this list of tests to perform is prioritized so that the most accurate field analysis is obtained:

1. Presence of water
2. pH
3. Temperature
4. Dissolved CO_2
5. Dissolved H_2S
6. Alkalinity
7. Bacteria density

The presence-of-water test is performed using litmus paper. If the liquid being sampled is composed only of hydrocarbons, no further testing would be necessary. After confirming that the sample contains water, the pH and temperature of the sample should be measured. Next, the dissolved gases and alkalinity should be tested. Finally, the sample should have a bacterial dilution series set up. These onsite tests should be performed as quickly and safely as possible, preferably in the first 15 minutes after taking the sample. The bacteria must be inoculated within four hours of sampling (but preferably within the first hour) [2].

Solids

The following list for testing solids can be used whether the solid material was blown out of the pipeline, obtained

FIGURE 4. Metal coupons of known weights can be installed into the pipeline to determine weight loss by corrosion over time

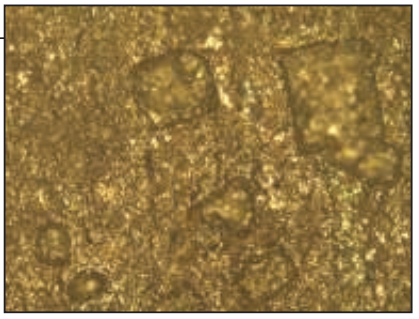

FIGURE 5. Evaluating-and-monitoring coupons can help reveal micro-pitting on surfaces

from a pigging run, or obtained by separating the pipeline:

1. Appearance of the solids
2. pH
3. Bacteria density
4. Onsite chemical testing

When air is introduced to a pipe, the material begins to oxidize, thus changing the chemistry of the solid material. This is why the solid material should always be visually inspected as quickly as possible, before oxidation occurs and changes the appearance of the solid material. Then the pH testing should be performed, along with processing the solid for bacterial analysis, as this material can be a breeding ground for bacteria. Finally, any additional onsite chemical testing can be performed. The sample should then be placed into a container that minimizes the amount of airspace, to slow the oxidation of the sample.

Gas

For gas sampling, the following onsite tests can be performed with stain tubes for the water vapor and the acid gases:

1. Water vapor
2. Acid gases
3. Temperature
4. Pressure

When performing sampling for laboratory analysis of the acid gases, the correct type of container needs to be used. For CO_2 and O_2, standard carbon-steel cylinders can be used, but if H_2S is to be analyzed, the sample cylinder needs to be lined or treated so that the cylinder itself does not react with the H_2S and corrupt the sample analysis. Also, when using sample cylinders, be sure the pressure rating of the cylinder is sufficient to handle the pressure in the system being sampled. Gas sample locations should be in areas that are representative of the system being sampled. The locations need to be accessible for repeat sampling, as well. Lastly, care should be taken to avoid liquids — either water or liquid hydrocarbons — in the sample cylinder, as this material will damage the analytical equipment.

Coupons and probes

Coupons and probes are also used to measure potential corrosion in pipelines. Coupons can be as simple as basic weight-loss coupons where a clean known-weight metal coupon is installed into the pipeline for a period of time between 30 days and six months (Figure 4). The coupon is then removed, cleaned and reweighed. A calculation is then performed that yields the weight loss over time, expressed in milli-inches per year (MPY).

On the advanced end of the spectrum are evaluating and monitoring (EM) coupons [*3*]. These coupons are specially prepared to have a very smooth surface for microscopic analysis. The EM coupons are installed for short durations, and when removed, the EM coupon is set up through a specific set of preparations so that it can ultimately be embedded in acrylic resin to preserve any bacteria on the surface of the coupon. The resin is then removed from the coupon, and the coupon is cleaned. After the cleaning process, the coupon can be weighed to obtain a weight loss. The coupon can then be microscopically scanned.

These scans are used to evaluate micro-pitting (Figure 5). The acrylic resin is also scanned microscopically to determine if any bacteria were attached to the coupon that would correlate to areas of micro-pitting. The EM coupons are used to determine corrosion initiation mechanisms or to perform bacterial-kill studies (Figure 6). Some other common coupon types are as follows:

- Oxygen coupons — for short-term monitoring of concentration cells
- Copper ion displacement (CID) — for monitoring chemical distribution

Probes, in general, give realtime corrosion rates. These types of sampling tools can be a good choice if the material in the system is aggressively corrosive or the system is in a critical area that can benefit from realtime sampling. The two most common types of probes are the following:

- Electrical resistance (ER) probes — for realtime monitoring of vapors and gases
- Linear polarization resistance (LPR) probes — for realtime monitoring of liquids

Probes can be installed in many different configurations for collecting corrosion data. The probes can be installed so that an electronic reader has to be utilized to take a measurement, or data-loggers can be connected to the probes so that corrosion measurements can be logged at preset intervals. The probes can also be set up to transmit realtime data via SCADA, cellular or satellite networks.

Establishing baselines

Inline inspections consist of many different types of tools to determine if there are any anomalies in the system being inspected. These tools can be as basic as an ultrasonic gage used on the outside of the system, or as advanced as inline inspection tools (smart pigs). These smart pigs have the ability to find and quantitatively measure corrosion that has already occurred. These tools are good for obtaining a baseline of any corrosion or anomalies in the system. With the baseline established, the other sampling techniques discussed herein can be used to measure the potential for corrosion. Then the inline inspection tool can be re-run to determine if any of the mitigation techniques used were useful in mitigating the corrosion.

Lastly, a well-trained and educated sampling technician is essential to collecting quality samples and field data. Proper education and training can be achieved by industry education programs, company training, or performing sampling with another properly trained individual. NACE International (Houston; www.nace.org),

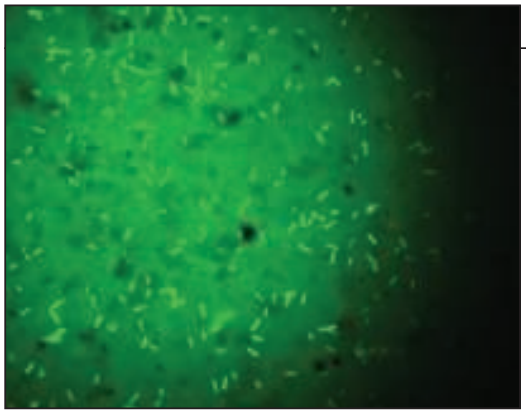

FIGURE 6. The presence of bacteria may correspond to areas of corrosion-induced micro-pitting on surfaces

the American Gas Assn. (AGA; Washington, D.C.; www.aga.org) and other organizations have developed internal corrosion-specific classes that go hand-in-hand with federal, state and industry standards for sampling, testing and mitigation of internal corrosion.

Even with the proper initial training, it is important to obtain continuing education. No matter how well versed sampling technicians become, they should always approach every sampling event without assuming an outcome. The goal is to be a detective who collects all available information in a standardized format in order to paint a clear, concise picture of the sampling environment.

It is important to remember that each of these sampling techniques represents a piece of the analytical puzzle, and that none of these methods can stand alone. Sampling methods should be chosen to complement each other so that a complete picture of the internal environment of the asset or system in question can be formed. In this way, quality data can be gathered and studied to better assist the corrosion engineer in developing an internal-corrosion mitigation plan. ■

Edited by Scott Jenkins

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All photos: Charles Ross & Son Co.

FIGURE 1. A two-wing anchor agitator is a cost-efficient answer to limited flow within a mix vessel. For batches up to approximately 200,000 cP, the anchor can generate significant flow, accelerate the dispersion and hasten progress toward batch uniformity

Feature Report

The Unexpected Rewards of Testing a Mixer

For custom mixers and blenders, verification is only one benefit. Testing can open the door to further improvement

Ken Langhorn
Charles Ross & Son Co.

Among all the engineers who will be involved in the purchase of a mixer or blender next year, roughly half will welcome a change in their production method. The other half will be determined to prevent it.

Searching for the right equipment to make a new product or boost current production, about 50% of users will conduct open-eyed tests in the laboratory of a mixing equipment manufacturer.[1] They will test a variety of mixers and ancillary equipment. While manipulating parameters such as shear, viscosity and flow rates, they will experiment with various types and combinations of agitators. They will explore the effects of applying vacuum or altering batch temperature at certain stages of the mix cycle.

Another 25% of users will conduct tests, but their mission will be due diligence, not exploration. Their goal will be to control risk by collecting data and confirming an equipment selection prior to committing to a purchase or rental. In other words, they want to avoid making an expensive mistake.

The remaining 25% will not test at all. Relying on long experience with familiar equipment and a well-understood application, they will replace worn-out equipment (or perhaps scale up) with the same equipment as before, intending only to replicate their existing process.

Who tests, and who should

The decision to test often reflects the personal attitude of a key manager or the collective values of a management team. Some welcome the challenge and potential rewards associated with change, while others prefer the security of continuing to operate "the way we've always done it."

Corporate culture and the company's competitive situation can also influence the desire to test. Some companies promote an aggressive, unrelenting search for every possible competitive advantage. Others — especially those businesses that haven't yet been pressured by global competition — are more complacent.

In fact, every manufacturing company must balance the opposing goals of innovation versus consistency, creativity versus predictability, change versus no-change. In most companies, change is welcome during product development but unwelcome afterward. After all, we all know that innovation is the engine of product development. It requires an open-minded approach to equipment selection, and this often includes equipment testing.

But on the plant floor, consistency is paramount. The traditional approach to production is to apply highly consistent techniques to manufacture a consistent product, while cutting costs and scaling production to meet demand. This usually includes standardizing the equipment used on the plant floor. As demand grows, scaleup generally means adding larger models of equipment already in use. When a piece of equipment wears out, it is replaced with a newer version of the same unit, based on the expectation that it will perform exactly as its predecessor did.

This reverence for consistency and stability in production has been the norm for many years. But intensifying competition in our global economy may call for a change of heart, especially where mixing equipment is concerned.

The trouble with disciplined consistency in production is that mixing technology is constantly evolving. In some equipment categories, such as high-shear rotor/stator mixing, high-speed powder injection and high-viscosity planetary mixing, the change during just the last few years has been profound.

As mixing technology has advanced, the capabilities of even the oldest and most familiar types of mixers have expanded — along with our understanding of how they can be used and what they can accomplish. Applications that were once considered appropriate for only one type of mixer can now be accomplished with a variety of equipment strategies, each offering a unique combination of advantages and disadvantages.

1. The mixers and blenders we consider in this discussion belong to the broad category of "custom" mixers and blenders – not standard, off-the-shelf turbine and propeller mixers that are regularly purchased without any need for testing.

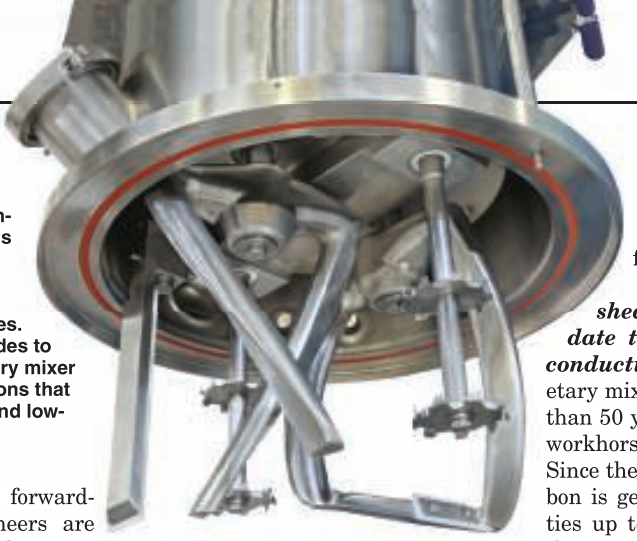


FIGURE 2. This double planetary/disperser hybrid mixer is equipped with a pair of high speed dispersers on each of two shafts, in addition to two sets of helical planetary blades. The addition of disperser blades to the traditional double planetary mixer enables it to handle applications that include both high-viscosity and low-viscosity stages

Recognizing this, many forward-thinking production engineers are now testing periodically, and not just when a plant expansion or the addition of a new production line provides an obvious opportunity to upgrade. They test to stay current on new developments in mixing technology, explore opportunities to improve both current and future production lines, and to make sure their companies remain in the passing lane of global competition.

Go with the flow

Many engineers who visit the test laboratory of a mixer manufacturer are surprised by the fact that subtle changes in a mixer's configuration or operation can yield an enormous improvement in performance. Virtually all arrive with at least an idea of the type of mixer they want to use, and often their instincts turn out to be correct — with the simple addition of another agitator.

Example 1: Adding a low-shear agitator to create a uniform pigment dispersion.[2] The production engineer in this case had used a high speed disperser for years to disperse a variety of liquid pigment blends in a base material. Operating in a batch with a lotion-like consistency — a viscosity of approximately 20,000 cP — the disperser provided plenty of shear energy. A 10 h.p. disperser in a 50-gal batch required about 60 min to complete the dispersion. Trials were arranged to search for potential improvements related to blade size and design, and perhaps the use of multiple blades mounted on a single shaft.

At this batch size and viscosity, an 8-in.-dia. high-speed disperser operating with a tip speed of 5,000 ft/min creates only a mild vortex. Pigments added to the light-colored base material provide a vivid display of uniformity — or in this case, slow progress toward uniformity. Material near the disperser was quickly dispersed and assumed a uniform appearance. Meanwhile, slow-moving swirls of color near the vessel wall indicated limited flow within the batch.

In actual production, the cycle time for this application had been 60 minutes, but most of that time was wasted. The mixer dispersed the pigments immediately once they contacted the blade. The limiting factor was the flow within the vessel, not the blade design. We recognized that flow could be improved by adding a low-shear agitator that would complement the action of the high shear agitator.

In a dual-shaft mixer, a slow-turning, two-wing anchor agitator improves flow by moving material from the vessel wall toward the high shear agitator (Figure 1). Teflon scrapers prevent a layer from remaining on the wall and bottom of the vessel. By improving flow, the anchor essentially feeds material to the disperser and accelerates the dispersion process.

With the complementary action of these two agitators, the batch reached target uniformity in 15 min, a 75% improvement compared to the cycle time required by the disperser operating alone.

An agitator for each stage

Mix cycles can often be accelerated by identifying key inflection points during the process and recognizing the need to apply different forms of agitation during different stages. Substantial changes in viscosity, for example, generally distinguish one mixing stage from another and signal the need for a change in agitation.

Example 2: Adding a high shear agitator to accommodate the lowered viscosity of a conductive coating. The double planetary mixer has been around for more than 50 years, and it is still a reliable workhorse for high-viscosity mixing. Since the dispersion of conductive carbon is generally processed at viscosities up to about 1 million cP during the mix cycle, it is a typical application for the double planetary mixer. In this scenario, a manufacturer had already used double planetary mixers to prepare conductive coatings. He scheduled a test to confirm the choice of a new mixer for scale-up.

Replicating the process in the test laboratory, conductive carbon powders were added to a solvent base, along with a variety of binder materials. Planetary mixing required 20 min of kneading at 1 million cP.

The next phase of the process was far more time-consuming. Letting the batch down from 1 million cP to 10,000 cP required 90 min, because the solvent must be added slowly. Dosing the solvent gradually allows it to be incorporated without forming clumps of the conductive paste, which bob in the low-viscosity mix and resist breaking down further.

The slow pace of the let-down stage of this cycle made it an excellent target for improvement. The key was to understand that it was slow only because the mixing action of the planetary blades became steadily less effective as viscosity fell. At viscosities below 200,000 cP, planetary blades generate very little shear and are unable to incorporate the low-viscosity diluent into the paste.

The solution was to switch from a traditional double planetary to a double planetary/disperser hybrid mixer (Figure 2). This mixer extends the versatility of the double planetary mixer by adding two disperser shafts, each of which can be equipped with one or two disperser blades. These high-speed agitators orbit the vessel in tandem with the planetary blades and apply intense shear.

In this application, the high-shear agitators were turned on for the

2. All of the test scenarios in this article are drawn from actual trials in the Ross Test & Development Center in Hauppauge, NY. However, certain details were omitted or changed to safeguard customer confidentiality or clarify the essential message of the example.

let-down, when the batch viscosity reached 200,000 cP, and they became steadily more efficient as the batch viscosity dropped further. The dispersers easily disintegrated all clumps of paste, and the 90-min let-down stage was shortened to 15 min.

Sometimes more is less

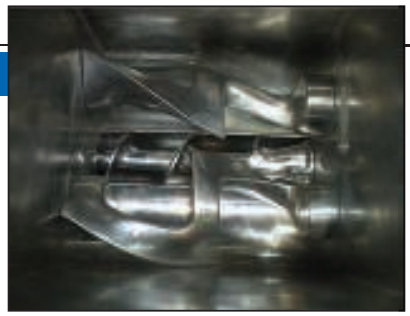
Successful laboratory tests are generally characterized by such measures as a faster mix cycle, a finer emulsion or dispersion, improved end-product quality, or increased efficiency (the result of combining multiple process steps in a single machine, for example). But sometimes a test can be called a success after producing no visible signs of product or process improvement — and even after requiring more pieces of equipment to achieve the same effect as before.

Example 3: Mixing high-viscosity polymers with less costly equipment. With high tensile strength and elasticity, flexible polymer blends are used in many industries to make a multitude of extruded products. They are commonly mixed in a sigma blade mixer, which applies enormous pressure to crush the polymer pellets while generating enough friction and heat to melt the polymers in a 15-gal batch in about 20 min. The mixing that follows requires another 20 min.

The sigma blade mixer (Figure 3) is immensely powerful, and with the batch viscosity at about 5 million cP, this application is hardly challenging. But it is also a particularly expensive mixer, so it is the best choice only when the viscosity exceeds the capabilities of all other mixers. In fact, the customer in this case had been using sigma blade mixers because he believed there was no alternative.

Our test strategy was to apply recent design advances in planetary blade design that have extended the working capacity of double planetary mixers well above their previous working limit of about 2 million cP. Equipped with helical blades (Figure 4), a double planetary mixer can handle viscosities up to 8 million cP, which makes it an attractive alternative to the sigma blade mixer in many applications.

Compared to traditional, rectangular planetary blades, the new generation of blades is helical and precisely sloped. The graceful slope enables the helical blades to pass one another with a slicing motion in the vessel. This prevents the sudden spike in power that typically occurs when the vertical arms of rectangular blades pass one another in a high-viscosity batch.



FIGURES 3 and 4. Sigma blade mixers (above) apply great power to mix materials at extremely high levels of viscosity. Recently, however, innovative helical blades (right) have extended the working viscosity of double planetary mixers significantly. This has made many high-viscosity applications appropriate for either a sigma blade mixer or a planetary mixer

By suppressing this power spike, the working viscosity of a double planetary mixer equipped with helical blades extends well beyond the 5 million cP level this application requires. But in this case the planetary mixer required additional equipment to melt the polymers before mixing could begin.

This test was conducted in a 40-gal double planetary mixer with thermal jacketing, through which we circulated oil at 350°F. The polymers required 20 min to melt and another 20 min to mix. They were then discharged with a hydraulically actuated, automatic discharge system.

The test results included no change in cycle time or product quality, and the test required three pieces of equipment where one had been used before. But it was clearly successful because the total cost of the new system was more than 50% lower than the cost of a new sigma blade mixer.

Advantages of pre-milling

Preconceptions built over many years of practice are often hard to dispel. In a test environment, they can be especially costly if they are allowed to discourage exploration. Engineers who are willing to consider unfamiliar technologies and unexpected solutions are often rewarded with quantum improvements in production.

Example 4: An ultra-high shear pre-mill makes downstream media milling unnecessary for an aerospace pigment dispersion. Media mills are a common sight in plants producing fine dispersions. They can produce excellent results, but they are also notorious for their slow throughput and the laborious cleaning and maintenance they require. To address these shortcomings, high-speed rotor/stator mixers are commonly used to pre-mill materials, reduce particle size significantly, and shorten the cycle time required by the mill.

This test was arranged to measure the performance of a traditional, single-stage high-shear mixer serving as a pre-milling device (Figure 5). To produce an aerospace coating, the engineer had been pre-mixing pigments and an epoxy-based material in a disperser-agitated vessel, then sending the mix downstream to the mill. His goal was to save time and increase production by feeding pre-milled material to the media mill.

The first test using the single-stage rotor/stator mixer was successful. A single pass through the inline mixer, operating with a rotor/stator developing tip speeds of 3,500 ft/min, easily met the target particle size.

A second test explored the performance of a completely different rotor/stator concept, and the results were even more dramatic. This time, the pre-mix was fed through an ultra-high-shear inline mixer (Figure 6).

Unlike the traditional single-stage high shear mixer, the rotor/stator generator in the alternative setup does not include conventional blades. Instead, the rotor and stator are comprised of

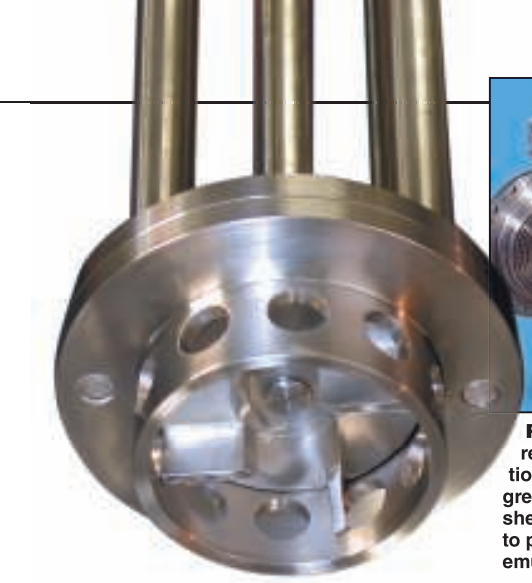


FIGURE 5. In the single-stage high shear mixer, a high speed rotor turns within a fixed stator, applies intense shear in the high shear zone and expels material radially through holes or slots in the stator. Available in either batch or inline configurations, this mixer has been used for many years to pre-mill dispersions prior to media milling

FIGURE 6. This rotor/stator generator represents a sharp departure from traditional rotor/stator design. This innovation greatly extended the application of high shear rotor/stator mixers by enabling them to produce much finer dispersions and emulsions

FIGURE 7. This batch-configured high shear mixer is equipped with a wand and feed tube that terminates beneath the surface of the batch. Powders are sucked through the tube and injected directly into the high shear zone, where they are dispersed instantly

many concentric rows of intermeshing teeth. The mix material begins at the center of the generator and moves outward through the rotor/stator teeth. With extremely close tolerances and high tip speeds (up to 18,000 ft/min), the shear applied to the material in each pass is extraordinarily intense.

In this test, the ultra-high-shear rotor/stator mixer produced a "premilled" product that met the specification for final production in the media mill. The low-flow, high-maintenance mill was replaced by a high-flow, high-speed inline mixer. Overall production was increased and long-term operating costs were cut significantly.

A fast remedy for fish eyes

A simple switch to a more aggressive mixer design — from a low shear propeller or turbine to a high shear rotor/stator mixer, for example — can yield startling results. But in many cases, to optimize the mixing process, a high shear generator must be accompanied by an auxiliary device that delivers raw material directly to the high shear zone.

Example 5: Dispersing powders with sub-surface injection turns an overnight chore into a 5-min. process. Gum thickeners are used by process engineers worldwide to make a multitude of products from doughnut fillings to the electrodes in flashlight batteries. They are extraordinarily versatile, but they are also frustrating to work with, because they are extremely hard to hydrate uniformly.

Instead of dispersing easily, most gum thickeners float on the surface of a liquid batch. Even when a high-shear mixer is used to generate a vigorous vortex, the powder will float persistently, occasionally forming bulging "fish eyes," turning slow circles around the rim of the vortex as it stubbornly sinks into the liquid.

The engineer in this case followed the century-old custom of adding gum thickener to a water-based mix, in a vessel equipped with a propeller, and letting it run overnight. By morning, the gum had finally dispersed and the mix was ready for the next step. A test was arranged to assess the value of replacing the propeller with a batch rotor/stator mixer.

In a 100-gal vessel, a 10-h.p. high-shear mixer created a high quality dispersion and reduced the mix cycle from 8 h to 1 h (Figure 7). To anyone who has seen a rotor/stator mixer in action, this was actually not surprising.

A second test included a similar rotor/stator mixer, but this one was equipped with a sub-surface powder injection device. The device sucked the free-flowing powders through a tube that delivered them — still dry — directly to the sub-surface high-shear zone of the mixer, where they were dispersed immediately. For a 2% concentration of gum thickener, the system injected all 16.7 lb of powder and completed the dispersion in 5 min.

Maximize the value of testing

Process engineers who do not step away from their process lines periodically to reassess their mixing equipment strategies are assuming significant risk, especially in highly competitive markets. As mixing technology continues to evolve, each advance you overlook may wind up on the plant floor of your competitors. And, as we have seen, even seemingly small changes in your equipment configuration or mixing technique can yield a significant improvement in production — and an important competitive advantage.

The best course is to visit the laboratory of a mixer manufacturer and test using your own ingredients. Replicate your process environment as closely as possible. Choose a laboratory that provides onsite analytical evaluation of your test results, so you can modify your testing in realtime, based on quantitative results.

Most important, be sure to test a variety of equipment, not just the equipment you expect to purchase or rent. In order to discover unexpected success, you'll have to explore some unfamiliar territory. ■

Edited by Rebekkah Marshall

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Evaluating Green Projects:
Modeling Improves Economic Benefits

Allen Williams, Private Consultant
Ken Dunwoody, Retired

The use of dynamic modeling can help to identify the engineering and economic feasibility of any proposed project. This sample project, involving the conversion of solid waste to synfuel, shows how

The ability to model a process to see if it meets project requirements and is economically viable enhances the conceptual design. Modeling gives engineers a means to identify the most promising processes, in terms of capital investment and return, and this can be particularly important when the project is environmentally oriented (a so-called green project).

Did you ever consider producing a new product from your existing plant inventory, or implementing a particular green project that could help to reduce your tax liability but for which high fuel costs ultimately killed the overall economics of the project?

It is important to evaluate green ideas that could potentially improve your bottom line, but how do you sort through a myriad of computations to screen all the options associated with such tasks, and evaluate the pros and cons of each proposed idea?

The answer is simpler than you might think. The trick is to use a dynamic process model that is equipment-specific but still generic in the way that it handles mass and energy computations. Today, while there are a number of commercial models available, there are many benefits that come from building your own real-time dynamic model — one that can allow you to assess your process and its associated controls.

Dynamic modeling platforms are available with most distributed control system (DCS) hardware, but in many cases, a PC-based system model provides the greatest versatility and flexibility. Specifically, building your own computer process allows you to customize the functions and tailor the model to fit your site-specific application and this provides a smoother way to manage project change.

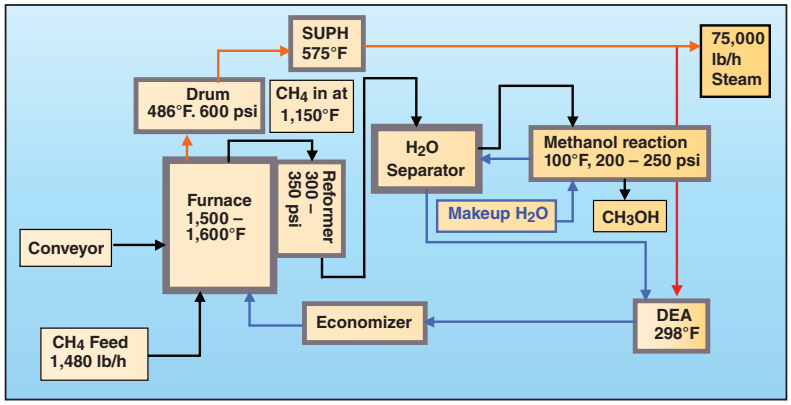


FIGURE 1. Shown here is a typical process sketch for a solid-fuel-fed steam reformer and methanol reactor. The hydrogen and carbon monoxide blend are reacted to produce methanol (SUPH = super heater; DEA = deaerator)

Developing your own process model is not as daunting a task as it may first seem, especially if you define the modeling system and identify what is required before tackling the process. And, your time investment will be paid off by increased analysis proficiency, speed and capability. A model with greater analytical capabilities allows users to explore more alternative scenarios, in greater detail.

Operating data and physical constants define the boundary conditions that determine how well a model represents an actual process. But, don't expect extraordinary or three-decimal-place accuracy in computations — rather, such models are useful for identifying trends and direction of changes. Most rudimentary modeling efforts will fall within ±10%. More-thoroughly-developed algorithms can attain accuracy of ±1–3%.

The process

To begin, make a short sketch of the selected process (such as that shown in Figure 1). Identify the temperatures, pressures and flowrates for each segment that is to be modeled. Such a conceptualization sketch must include key state variables, such as component concentration, moisture content, levels of excess oxygen in the furnace and so on.

The process model profiled here emulates a 100- to 125-million-Btu/h industrial combustor with feed preheating, a deaerator, an economizer and a solids-conveying system. A green project idea proposes to use the system to produce synthetic fuel from municipal waste.

The process is represented by a set of ordinary differential equations that conserve mass and energy, and utilize thermodynamic relationships, reaction kinetics and authentic equipment

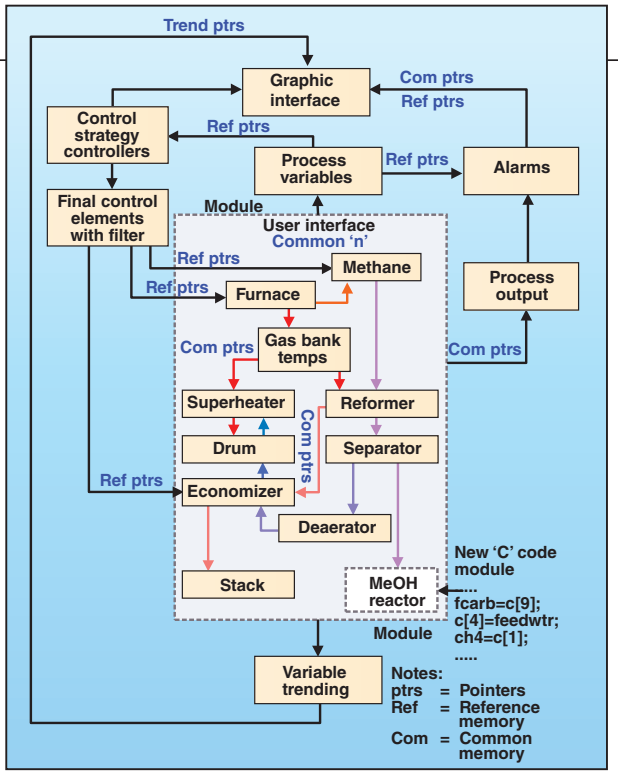


FIGURE 2. This figure shows the dynamic model environment, identifying dedicated segments and interconnections within the 'User' Interface. The simulated process information moves between segments

ECONOMIZER SEGMENT

```
/*.....Economizer Segment.....*/
/* Source code as it should appear in the 'C' editor */
Re = 4 * Wfw/(*(Di/12)*Mu*ntube);      /* Liquid Reynold's No */
Pr = cph2o*Mu/Kl;                      /* Prandtl No. */
tsat = a+dp*(b+dp*(c+dp*(d)));         /* Saturated temp at drum pres */
tavg = (tw + tdea)/2;                  /* Avg temp across economizer */
kw = 345 -.077*tavg;                   /* TC data - .23 C.S. , 1972 B&W */
                                       /* STEAM, p. 4-2, Fig. 1 */
Rtube = Do/12 * log(Do/Di)/(2*kw);     /* Tube therm resistance */
                                       /* from 1972 STEAM p.4-9 */
Re = wflue/Af*(Di/12)/ugas;            /* Gas Reynold's No, STEAM, Chap 4 */
                                       /* Where: wflue/Af is the bulk gas velocity */
Pr = cpflue * ugas/kgas;               /* Gas Prandtl No. */
Hid = 0.023*Kl/(Di/12)*(4*wfw/(*(Di/12)* uliq * ntube))^.8 *Pr^.4;
kair = (a + b*dty)/12;                 /*Regress fit of air thermal cond */
/* Where: 'dty' is the differential gas bamk temp entering the economizer */
kgas = xrh2o* kh2o +(1-xrh2o)*kair;    /* flue gas therm Cond */
Ucg = a1*kgas*Re^.61*Pr^.33;           /* Gas ht-trans, 1972 STEAM, Chap 4 */
U = 1/((Do/Di)* 1/Hid + Rtube + Ucg;   /* Overall Heat Trans coeff */
q = wflue * cpflue *(ty - ta);         /* Heat added by flue gas */
area = ntubes * Ltube * Ao;            /* Gas outside tube area A0=ft2/ft */
dtw = tdea – tw +q/(area*U);           /* T(i+1) = F(n) T(i) / F(n') T(i) */
tw = tw + dtw;                         /* Integrate Economizer Outlet temp */
cph2o = a + b* tavg + c * tavg^2;      /* Economizer ht-capacity */
q = wfw * cph2o*(tw - tdea);           /* Heat added by the flue gas */
t a v g = ( t w + t d e a ) / 2 ;
cph2o = a + b * tavg + c * tavg^2;     /* Economizer ht-capacity */
q = wfw * cph2o*(tw - tdea);
dta = ta - ty -q/(area * U);           /* T(i+1) = F(n) T(i) / F(n') T(i) */
ta = ta + dta;                         /* New Econ Bank outlet temp
```

specifications to develop the model profile. In our example, solid fuel pellets are conveyed from a feed bin onto a furnace-traveling grate. Calcium carbonate is injected above the combustion area as an SO_2 absorbent.

Methane feed enters the first of two preheaters at 100+°F and is heated successively in two stages from 950°F to 1,150°F. The hot methane feed enters a HYCO reformer where 600-psi steam is added. The HYCO gas — which is comprised of carbon monoxide, hydrogen, and unreacted steam — passes from the reformer to a water separator. Steam condenses out in the separator and the remaining dry gas flows from the separator tank to a catalyzed reactor that operates at 100°F and 200 psi to produce methanol.

Makeup water at 77°F cools the methanol reactor and is pumped to the separator tank, where it is mixed with hot condensate from the HYCO reformer and sent on to the deaerator. Oxygen is steam stripped from the feed water in the deaerator at 298°F before entering the economizer.

The model unit is designed to operate at 1,500°F with 18% excess air and negligible air preheating.

The model

Once you have established a good process definition, the next step is to begin to develop an outline of the model 'C' coding, adding external references and variables, as needed. 'Pseudo code' is preferred at this stage. Be certain that supporting definitions and library functions are loaded.

When the pseudo code is complete, formalize and code the general and library routine statements into a main process module. Add separate segments, as needed, and name them according to their intended function (for example,the economizer segment, and so on).

Library routines containing other supporting functions must be called with an *#include* statement. For instance:

```
/*          MAIN SEGMENT          */

#include <math.h>                    /*
math subroutine library */
float Di, Do, Q, V, ts, tg, tsat;    /* local
floating pt single */

float Hg, Hid, Hod, Lhv, Hhv, Mu,
Ntube;  /* precision variables      */

....

extern double c[9], w[9];            /*
global double precision   */
```

(Note: All terms are defined in the Nomenclature box on p. 37.)

Entering comments or reminders into the code language for future reference is highly recommended. For

instance, comments can be added directly into the computer code as shown above, according to the software vendor's programming convention.

Double-precision variables should only be used when a floating-point accuracy of greater than 8 bits is required — for instance, in the calculation of heater-tube fouling coefficients that involve very low numbers (that is, less than 1E-04).

Calculated heat and mass transfer data should reside in common memory. State variables that are to be used as process inputs must be linked to the controller-measured variable.

Whatever dynamic modeling platform you select should support this approach. The ability to make coding modifications and additions within a model are greatly facilitated when you do not have to re-allocate variables. Figure 2 shows how the code segments are configured to pass information to one another.

STEAM SEGMENT

```
/*..... Steam Drum segment..... */
Hg =a + dp *(b + dp *(-c + dp *(d));      */ Stm enth @drum pres curve fit */
Ub = 4000/(2.515*dtsat^.33));             /* Peters & Timmerhaus, 2nd edition */
dw =(Ub*wfw/Rf)/(Hv*b1-2*c2*tb)*dtsat/(tsat-tw);          /* diff lb/hr evap */
tavg =(tsat + tw)/2;                      /* Avg mud drum and Sat liq temp */
Kw = 345-.1*tavg;                         /* .23 CS, STEAM - p. 4-2, Fig 1 */
area = ntubes*Ltube*Ao;                   /* Gas outside tube area Ao=ft2/ft */
R = dx/(kw*Alm);                          /* Perrys 4th Ed, Tube Chart - Table 11-2 */
Uo = Ub +1/R; .                           /* Overall Boiling Ht Transfer Coefficient */
wstm = wstm + dw;                         /* Steam mass evaporated */
q = wstm * (Hg - Hf);                     /* where Hg - Hf is the ht of vaporization */
qfr = wflue * cpflue *(tf - t0); dt0 = tf - t0 - (q + qfr)/(area*Uo);   /* T(i+1) = F(n) T(i) / F(n') T(i) */
t0 = t0 + dt0;                            /* New water drum gas bank outlet temp */
```

SUPH STEAM SEGMENT

```
/*..... Super heater segment ..... */
Rtube = dx/(kw*Ao);                       /* Perry's 4th Ed, Tube Dia, Table 11-2 */
Re = wstm/Af *(Di/12)/uvap;               /* Steam Reynolds No. */
Pr = cpstm * uvap /kv;                    /* Steam Prandtl No. */
Hid=0.023 * RE^.8 * Pr^.4)/(Di/12)^.2;                  /* STEAM, 1972 - Fig 6, p. 4-8 */
RE = wflue/Af *(Di/12)/ugas; /* Gas Reynold's No */
Pr = cpflue * ugas/kgas;
Ucg = a2 *kgas*pow(RE,0.61)*pow(Pr,0.33)*Fa;            /* 1972 STEAM, Chap 4 */
U = 1/Rtube + 1/Hid + Ucg;                /* Overall Heat Trans coeff */
q = wflue * cpflue *(t0 - ts);            /* Gas bank energy input */
dtw2 = tb – tw2 +q/(area*U);              /* T(i+1) = F(n) T(i) / F(n') T(i) */
tw2 = tw2 + dtw2;                         /* Integrate Suph Outlet temp */
cpstm = a + b * tavg + c * tavg^2;        /* Integrate Steam Ht capacity */
/* where a, b, c are dimensionless ht capacity coefficients */
```

FURNACE SEGMENT

```
/*..... Furnace segment ..... */
Hhv = 10221;                              /* Waste-Blend heating value */
xc = 0.5297;                              /* fuel carbon content */
xh2 = 0.1048;                             /* fuel hydrogen content */
xsul = 0.0238;                            /* fuel sulfur content */
xo2 = 0.1300;                             /* fuel oxygen content */
xn2 = .0017;                              /* fuel nitrogen content */
xrh2o = 0.1467;                           /* wt frac of H2o in the waste fuel */
fuel = S ft/hr * w ft2 wide * d lbs/ft3   /* Solid waste feed - lb/hr */
Lhv = hhv -(1040*8.9399*2*xh2o+18*xh2o);                /* Lower Heating Value */
```

Building what you need

Once you have identified a green project to evaluate, pick the most common service elements. In the example profiled here, these service elements are the furnace, reformer and reactor. Other components can be developed and added later, as required.

Process data should be obtained from plant operations to develop the physical characteristics of the plant equipment being modeled. Professional handbooks and equipment specification sheets are good sources to provide representative data related to materials of construction, sizes, flowrates, and occasionally temperature and pressure.

When you cannot locate the exact information desired, relevant numbers can often be generated by manipulation. For example, heats of reaction can be found by adding and subtracting chemical equations from standard texts until suitable heat data are obtained.

Equilibrium rates for combustion reactions that generate emissions may be estimated from the catalyst manufacturer's K_f formation data. For example, in the case of predicting NOx emissions, Equation (1) can be used to calculate the heats of reaction for nitrogen dioxide by manipulating the heat of formation data to determine the combustion equilibrium constant K_p. (This approach lets users get the required rate data when exact information is not shown):

$$N_2 + O_2 \xrightarrow{1{,}500^\circ F} NO_2 \qquad (1)$$

The reaction equilibrium constant, K_p, is defined below:

$$K_p = \frac{pNO_2}{p(N_2)^{1/2}\,pO_2}$$

$$LogK_p = Log_{10}\sum K_{f\{prod\}} - Log_{10}\sum K_{f\{reactants\}}$$

$$LogK_p = -4.861 - 0$$

$$K_p = 1.37E-5 = k_1 / k_2 (\text{dimensionless})$$

The computed K_p values may be logarithmically plotted against temperature to give the reaction equilibrium constant, K, over the anticipated operating conditions.

Arranging code segments

Identify the process control streams that drive the model calculations. In this example, they are the solid waste fuel, feed water and methane flows.

Define the process segments, how

NOMENCLATURE

A, A_f, A_{LM}	tube areas, ft^2
A_o	tube outside area, ft^2/linear ft
CaO	carbon monoxide initial concentration, lb-moles/ft^3
CH_4	methane feed to the HYCO reactor
Cp_{co}	heat capacity of carbon monoxide product
Cp_{H2}	ht capacity of hydrogen product
Cp_{flue}	heat capacity of the flue gas
Cp_{meoh}	heat capacity of methanol product
Cp_{stm}	heat capacity of steam
C_V	valve flow coefficient, dimensionless
DEA	deaerator
D_i	inside tube diameter, in.
D_o	outside tube diameter, in.
dhwgs	heat of HYCO gas reaction corrected to reaction conditions
fco	carbon monoxide feed to methanol reactor
feedwtr	feed water flow to the deaerator
F_a	tube bank arrangement factor, dimensionless
F_{ao}	carbon monoxide initial feedrate, lb-moles/h
F_{carb}	steam to carbon ratio, dimensionless
F_m	methanol produced in reactor, lb/h
H_g	saturated vapor enthalpy, Btu/lb
H_f	saturated liquid enthalpy, Btu/lb
H_{hv}	fuel high heating value, Btu/lb
H_{id}	tube inside heat transfer coefficient, btu/h-ft^2°F
H_{od}	tube outside heat transfer coefficient, btu/h-ft^2°F
h_{rxnp}	Heat of reaction of HYCO gas products
h_{rxnr}	Heat of reaction of HYCO gas reactants
H_v	liquid heat of vaporization, Btu/lb
k_{air}	thermal conductivity of combustion air, Btu/h-ft-°F
k_{gas}	thermal conductivity of fluegas, Btu/h-ft-°F
k_{h2O}	thermal conductivity of the feed water, Btu/h-ft-°F
K, $K(1)$, $K(2)$, K_p	equilibrium constants, dimensionless
k_l	liquid thermal conductivity, Btu/h- ft^2-°F/ft
k_w	thermal conductivity for carbon steel, Btu/h- ft^2-°F/ft
k_v	steam thermal conductivity, Btu/h- ft-°F
L_{tube}	length of tube, ft
L_{hv}	fuel low heating value, Btu/lb
M_u	liquid viscosity, centipoise
n_{tube}	number of tubes
O_{pn}	model methane valve percent open, %
P, d_p	drum pressure and pressure differential
PID_{out}	model controller output, %
Pr	Prandtl number, dimensionless
Q	heat added to liquid, Btu/h
q	heat lost by fluegas, Btu/h
qfr	heat generated in furnace combustion, Btu/h
$R[dx/KA_{LM}]$, R_{tube}	thermal resistance to heat transfer, hr-°F/Btu
R_e	Reynolds number, dimensionless
R_f	saturated liquid specific volume, ft^3/lb
rxn	HYCO gas reaction rate, h^{-1}
stdh	standard heat of reaction
t_a, d_{ta}	economizer gas-bank outlet temperature and temperature differential
t_{avg}	average temperature across economizer, (inlet + outlet)/2
t_b	saturated liquid boiling temp
t_{dea}	liquid temperature in the deaerator
t_f	fuel flame temperature
t_j, d_{tj}	methanol jacket outlet temp and temperature differential
t_0, d_{t0}	water drum gas-bank outlet temperature and temperature differential
t_{sat}, d_{tsat}	saturated steam temperature and temperature differential
t_w, d_{tw}	economizer liquid outlet temperature and temperature differential
t_{w2}, d_{tw2}	steam superheater outlet temperature and temperature differential
t_s	superheater gas-bank inlet temperature
t_y, d_{ty}	economizer gas-bank inlet temperature and temperature differential
U, U_b, U_{cg}, U_o	Unit heat transfer coefficients, Btu/h-ft^2-°F
u_{gas}	fluegas viscosity, centipoise
u_{vap}	steam viscosity, centipoise
V	reactor volume, ft^3
w_{flue}	fluegas mass flow
w_{fw}	feedwater flow from the deaerator to the economizer
w_{stm}, d_w	steam generation flow and steam mass differential
x_c	fuel carbon content, wt. %
x_{h2}	fuel hydrogen content, wt. %
x_{o2}	fuel oxygen content, wt. %
x_{n2}	fuel nitrogen content, wt. %
x, x_m	unit conversions, mole %
x_{rh2o}	fuel moisture content, wt. %
x_{sul}	fuel sulfur content, wt. %

Note: All simulation temperatures are expressed in °F, pressures are in psi and liquid flow is in lb/h. Heat capacity is expressed in Btu/lb-°F, and heats of reaction are shown in Btu/lb-mole units.

they will be structured and how they will interact in the simulation. Figure 2 shows the methodology.

Next, assign inlet and outlet numbers or letters to the furnace banks for the estimates of model gas temperature so that model heat flow can be developed in the proper direction. The smaller arrows in Figure 2 depict information flow between the code segments.

The red arrows within the Figure 2 process module represent combustion gas temperature and information flow, while the blue arrows provide feed water condition information progression from the economizer to the steam drum and steam to the super heater (SUPH). The arrow color for fluegas decreases in intensity (from darker red to lighter red), to depict the corresponding loss of heat energy, in the data passed, as the temperature of the fluegas reduces through this series of coded segments. The magenta arrows in Figure 2 show the HYCO gas information progression from the methane preheat units to the methanol reactor segment. The model can be set up so that a particular segment's calculated information appears in a realtime graphical display.

Implementing the model code

The user interface of Figure 2 is a module made up of one or more 'C' code segments. Segments in the example module, because of their relatively small size, comprise the entire model user interface shown.

However, users working with larger furnace simulations — for instance, those with reheat and additional superheating components — may find it expedient to dedicate an entire module to one process function alone (that is, all code segments in that module are dedicated to a single task).

The selected simulation user interface should be able to contain multiple user blocks with individual discrete segments. Multiple user blocks must be able to pass information to other user blocks, just as if they were segments within the same module. The modules must be linkable to your control strategy in the chosen environment.

Once the model is structured and ready for coding, initialize all variables used in that segment before developing detailed computations, as shown in the furnace segment example for updating fuel composition.

One can develop the model for en-

ergy flow in either direction. In our example, we move from the coolest streams to the hottest ones.

Next, code the process variables that will be input to the model controllers.

Begin to develop dimensional data from unit hardware characteristics. The model should utilize the same number and size tubes as the prototype. The economizer segment typically shows how tube diameter, quantity and material of construction develop the heat-flow characteristics of the equipment being modeled.

Develop the liquid heat transfer coefficients using *Dittus-Bolter* or other accepted heat transfer expressions. Thermal conductivity data are readily available in physical property or commercial refrence texts and only need to be regression fit to use. However, for a smoother and quicker initial startup, develop gas bank heat transfer coefficients on thermal resistance alone, for example dx/KA until operational (see Perry's 4th Ed., Tube Char-Table 11-2, p. 7) and then enhance the overall heat transfer coefficient, U, with additional relationships.

The thermoconductivity (k_{gas}) of the fluegas is dependent on the fuel moisture content (xrh_2o) and water conductivity (kh_2o).

Furnace gas flow, w_{flue}, can be developed from combustion reactions, $C + O_2 \rightarrow CO_2$, using the composition data shown in Table 3.

Sum the fluegas components, (such as '*Co2*', '*H2o*' and so on) to get an updated w_{flue} based on model controller fuel flow. Integrate the individual fluegas heat capacities, at gas bank temperature t_y (to get the new cp_{flue}) before calculating the gas heat loss at the economizer.

Heat transfer area is a product of the number of tubes, length and the external square feet of area per foot of tubing.

Derive the necessary mathematical expressions and formulate the differential temperature relationships. To calculate the heat gained, integrate up the liquid heat capacity based on the average temperature of the economizer inlet and the new outlet temperature.

Update the economizer outlet-gas-bank temperature for the energy lost due to heating the feed water. The updated economizer outlet temperature (the term '*tw*') becomes the input to the furnace steam drum.

Estimate the differential steam mass '*dw*' evaporated by the furnace.

The overall heat transfer coefficient for the drum must include the inside tube boiling film coefficient '*Ub*', as previously described, so that the furnace exit-gas-bank temperature varies with the quantity of steam generated. This variance is then propagated to subsequent bank temperatures to develop an overall dynamic gas temperature profile (shown by the curved black line of Figure 3).

The overall heat transfer coefficient for this case is $U_o = U_b + 1/R$.

Calculate the heat required for the steam vaporization:

$$q = w_{stm} * (Hg - Hf)$$

Calculate the heat produced in the furnace combustion, '*qfr*' where '*tf*' is the flame temperature.

Derive the mud drum gas bank outlet temperature expression, '*dt0*' and formulate the differential temperature relationship:

$$T(i+1) = F(n)\ T(i) / F(n')\ T(i)$$

As developed in the economizer segment.

The steam evaporated from the drum '*wstm*' is the input to the super heater.

Thermal conductivity of the superheater steam tubes is the same carbon steel material '*kw*' as in the economizer tubing wall resistance, '*Rtube*'.

Continue updating other flue gas temperatures for energy lost due to heat transfer to the process, using the proper gas-bank number or letter codes, as was done for the outlet temperature of the economizer gas bank.

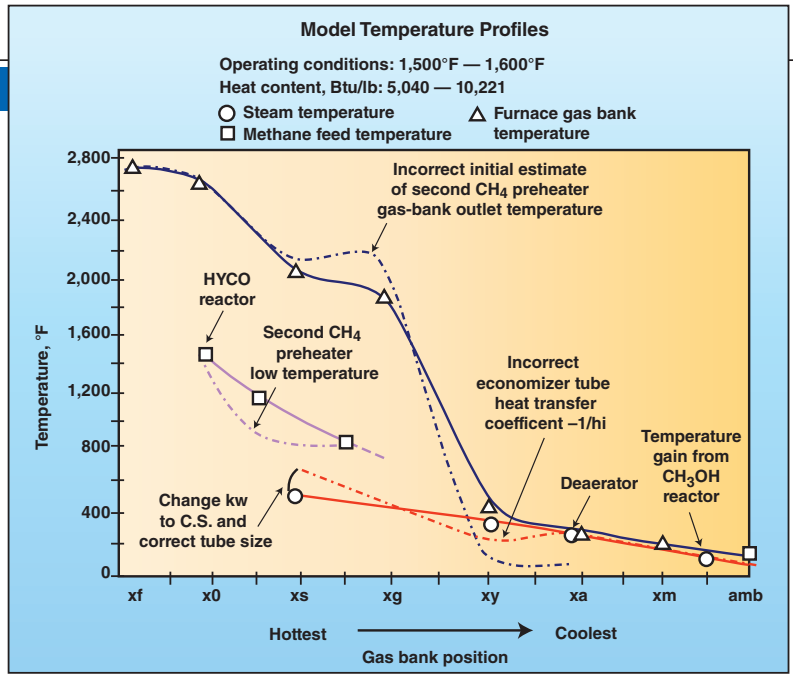


FIGURE 3. This figure is the model calculated temperature profiles for the process reference condition. The model temperature profiles determine whether or not the model material and energy balances are sufficiently representative of the prototypical process so as to be reasonably predictive. They are an essential tool for developing and troubleshooting any model process

TABLE 1. STEAM/CARBON RATIO TO CONVERSION

370 lb/h	18.0% excess air
T=1,500°F	9.3 MJ/kg = 4,466 Btu/lb
Steam/carbon ratio	CH_4 conversion, %
1.9	96.96
2.2	97.05
2.7	97.09
3.2	97.12
3.7	97.15

Kinetics

Kinetic data for equilibrium reaction rates can be obtained from catalyst manufacturers and from thermodynamic texts. There are two competing reactions in the HYCO process:

REACTOR SEGMENT

```
/*..... HYCO Reactor segment ..... */

K(1) = Exp(log(a)+ dt * log(c));          /* Log plot, Ka = k1/k2 */

K(2) = a - b * tout;                      /* Regress fit of catalyst data, Kb = k3/k4 */

V = ntubes * Ltube * Area; /* ft3 HYCO Reactor Volume */
rxn =a*(K*V*CaO)/FaO*c2 - log(b*c);       /*(a,b,c from 2nd Order kinetic Rx */
Hrxnp =(fco*cpco+fh2*cph2)*1.8*(tout-tref); /* Prod x 1.8 = Btu/lbmole */
Hrxnr =(fco*cpco+fh20*cpstm)*1.8*(tref-tout); /* React x 1.8 = Btu/lbmole*/
Dhwgs =stdh + hrxnp + hrxnr;              /* Std ht of react, Btu/lb-mole */
/* corrected to reaction temp */

/*..... Methanol Reactor segment ..... */

float ch4, feedwtr, fcarb ..;
fcarb = c[9];                             /* Steam to Carbon ratio */
c[4] = feedwtr;                           /* feed water flow */
ch4 = c[1];                               /* methane feed to HYCO Rx */
x = c[7];                                 /* methane conversion from HYCO */
Fm = xm * fco;                            /* lb/hr MeOH from HYCO Feed */
/* Where xm is methane conversion */
cpco =a + b*tout-c*tout^2;                /* ht capacity CO at HYCO outlet temp */
cph2 =a1 + b1*tout + c1*tout^5;
cpmeoh =a2 +b2*tj -c*tj^2;                /* MeOH liq assumed at H2o Jacket temp */
hrxnr2 =fco* cpco + fh2 *cph2)*1.8*(tref-tj); /* React @ Rx cond */
hrxnp2 =Fm* cpmeoh *1.8*(tj-tref);        /* Prod @ Rx cond */
dhwgs = stdh2 +hrxnp2 +hrxnr2;

U = 1/(dx/(kw*Ao));                       /* Perry CH.E, 4th Ed, tube Table 11-2 */

dtj = (rxn * dhwgs)/(U*area);             /* T(i+1) = F(n) T(i) / F(n') T(i) */

tj = tj + dtj;                            /* H2O temp to the separation tank */
```

TABLE 2. SHREDDED TIRE HEAT CONTENT ESTIMATOR

Basis	Comp, mol fraction	Lb	H Btu/lb-mole	Moles
C	0.5794	60	98095.51	0.0483
H	0.1558	16.128	19153.10	0.0773
S	0.0464	4.8	5903.80	0.0014
O				
N				
H_2O	0.1584	16.398		
Iron	0.0601	6.2222		
Total moles				0.1270
Total	1,000	103,55	123,152	Btu/lb-mole
			7,87	lb/lb-mole
			15,640	Btu/lb

(1) $CH_4 + H_2O \longrightarrow CO + 3H_2$

(2) $CO + H_2O \longrightarrow CO_2 + H_2$

Equilibrium reaction-rate data are readily available. Log plots of the rate data yields the equilibrium constants '*K1*' and '*K2*' for the competing reactions. The reaction area is the inside cross-section of the tube (ft^2/ft). The reaction rate '*rxn*' is a function of the equilibrium constant, initial concentration of carbon monoxide and feed to the methanol reactor. The value for '*rxn*' should be determined from appropriate kinetic expressions.

Next, develop the standard HYCO heat of reaction ('*Dhwgs*') from thermodynamic data at reference conditions plus the reaction enthalpy of the products minus the reactants at reaction conditions.

The heat of reaction, endothermic in this case, should be developed from a plot of *dH* versus *T* from catalyst manufacturer data, or from kinetic expressions, if real data are not accessible.Gas temperature at the reformer and the HYCO heat of reaction determine the reformer outlet temperature.

Methanol

Methanol is produced from a catalyzed HYCO gas reaction according to:

$$CO + 2H_2 \xrightarrow{cat} CH_3OH$$

After the furnace and reformer segments are operational, add the methanol reactor to the USER module, as shown in Figure 2, beginning with common memory, c[*], as illustrated in the methanol reactor code segment.

Equilibrium rate constants and heat of reaction are available from catalyst manufacturers and were curve fit for this example.

The overall heat transfer coefficient is similar to that of the HYCO reactor, except there is no external source of heat other than what the gas entering the methanol reactor contains.

The estimated methanol-reactor water-jacket outlet temperature is the product of the heat of reaction '*rxn*' and the standard heat divided by the transfer coefficient and the jacket area.

The methanol exothermic reaction provides about 109.8°F–77°F=32.8°F of temperature gain to the water separator mix of Figure 1.

After the 'C' process model has been written, it must be compiled and linked to the simulator's graphical interface according to the simulator vendor's procedures. Unit controls may then be configured, and testing can begin.

The chosen vendor's model platform should also support logic functions, such as digital input and output modules for development and testing of process and safety interlocks.

Control blocks

The selected dynamic simulator platform should permit manual or automatic control with loop tuning and choice of proportional (P), propor-

tional-integral (PI), and proportional-integral-derivative (PID), and ramp controllers along with variable trending. Control blocks must have configurable scan rate settings.

The simulated process should react identically to the prototype with proper scan settings. The rule of thumb is 1/4 second for flow loops, 1/2 second for non-critical loops, and 1 second for calculation blocks. Control loops must be faster than the simulated process.

Configure single-loop control initially in your process, adding any complex loops after the model is working properly. Our example has only one cascade loop on the furnace-conveyor feed; the rest are all single loops.

The differential equations will integrate to dynamic equilibrium from controller action, usually within three to five scan cycles.

Significant improvement in the operation of an actual refinery reformer unit was achieved using *Energy Management Control* (for details, see Ref. [4]) over competing schemes.

Final control elements

Control loops should utilize a final control element to the process. Valve recursion formulas can be determined from vendor-specific, equal-percentage data (available from Fisher, Valtek, Masoneilan or other comparable valve manufacturers). Vendor software should be used to size model control valves just as if they were actual valves; real '*Cvs*' give loops a better prototypical response.

As a rule, valve equations for control loops should be implemented externally to the process in a calculation block with a small time filter. This allows the process variable to change slowly enough for the controller to respond properly. It is much more difficult when final control elements are coded into a 'C' process module.

The option of '*X-Y*' plotting of model variables from a trend chart display is desirable.

Model verification

Gas bank temperatures should be obtained from design specifications for the particular furnace unit modeled, and values for materials of construction should reflect real component hardware.

Calculated values from model runs should be compared to equipment data-sheet values or literature pilot studies for similar operations (if available) to verify that compatible data are produced.

Plotting the model-generated temperature profiles is essential to ensure that the model provides a reasonable representation of unit operation. Temperature-enthalpy diagrams from manufacturers are also useful tools for establishing equipment-operating lines.

Figure 3 shows the model development progression and corresponding temperature profiles. The upper leftmost point in the figure is the estimated flame temperature.

Process operating lines should be relatively linear when the heat transfer relationships are correct. The dashed lines in Figure 3 indicate computation errors discovered in coding execution (the lower half of the methane line was omitted for clarity), while solid lines indicate corrected model performance.

The *Newton-Raphson* numerical method requires an initial estimate of the state variable(s) prior to execution. For instance, guessing an initial value within +/- 200 units of the actual number is often satisfactory.

However, incorrect initial temperature estimates for the second methane pre-heater temperatures (shown in Figure 3) created errors. For instance, a wrong initial pre-heat gas-bank temperature estimate (shown in the upper dashed curve of Figure 3) caused the methane feed inlet temperature to be higher than the outlet, and, in turn the pre-heat gas-bank outlet temperature to be higher than the gas bank inlet temperature. Lowering the initial gas-bank temperature estimate and raising the methane feed-temperature estimate corrected the problem and a workable temperature profile was achieved.

After correction, the second methane pre-heater temperature varied from 1,134°F to 1,175°F, depending on steam production.

The model's superheater outlet temperature was found to be 700°F, well above the 575°F generated by the prototype. As shown in Figure 3, a faulty tube size and material of construction led to an excessive economizer heat-transfer coefficient, which produced an unrealistic economizer inlet temperature (700°F). The thermal conductivity of the exchanger tubing was changed in the coding to carbon steel and the tube size increased to correct the discrepancy.

Unit prototype data indicate that the reformer is natural-gas fired, with the second methane pre-heater operating at 1,150°F. The unit typically produces 75,000 lb/h of 600-psi superheated steam at 575°F.

The corrected model predicted 75,470 lb/h of superheated steam at

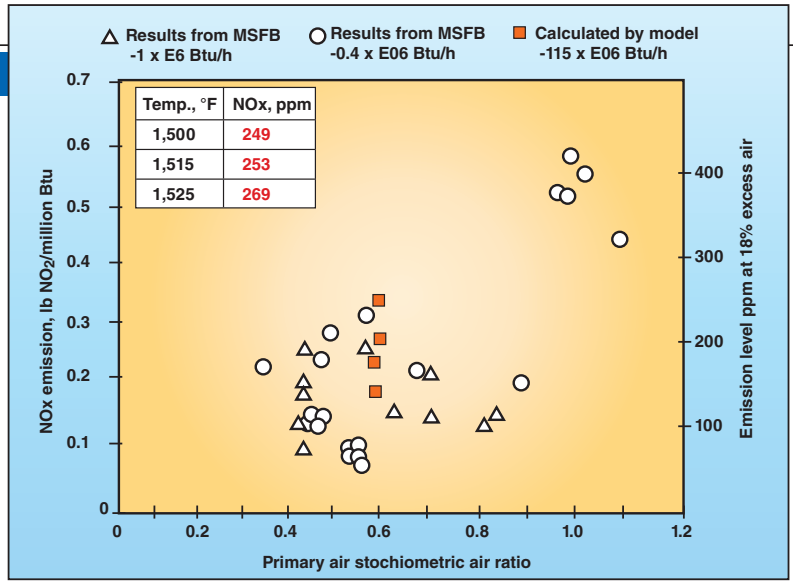


FIGURE 4. **'Effect of Excess Air on NOx Emissions [4]' shows the model-predicted NOx concentrations compared to actual pilot-plant furnace emissions levels. The predicted data correlate well with the prototype's 18% excess-air plotted conditions**

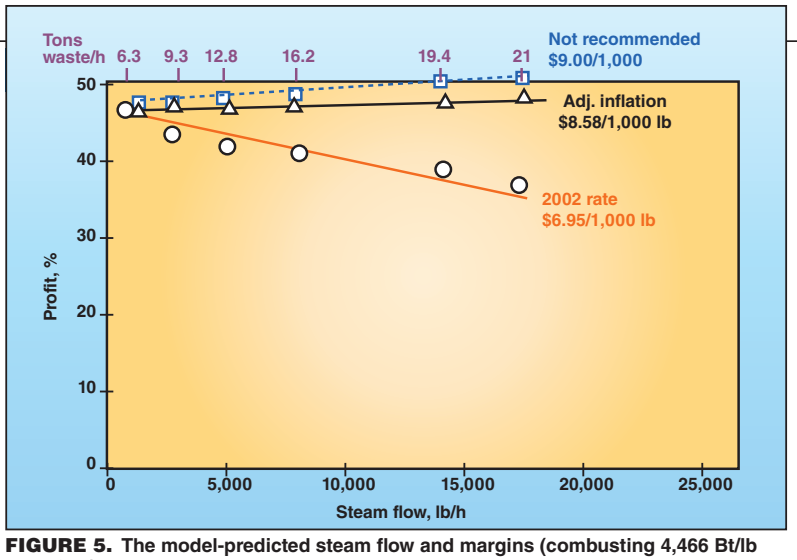


FIGURE 5. The model-predicted steam flow and margins (combusting 4,466 Bt/lb solid fuel) illustrate steam-pricing strategies applicable to the prototype

TABLE 3. BLENDED FUEL FOR MODEL EVALUATION

Basis	EPA 2005	Tires	2011 Blend		
Split	0.5	0.5			
	Waste	Tires	Composition	H Btu/lb-mole	Moles
C	0.48	0.5794	0.5297	89,674.82	0.0441
H	0.0538	0.1558	0.1048	12,887.32	0.0520
S	0.0011	0.0464	0.0238	3,024.80	0.0007
O	0.26	0	0.1300		
N	0.0034	0	0.0017		
H_2O	0.135	0.1584	0.1467		
Ash/solids	0.068	0.0601	0.0641		
Total, lbs	1.001	1.000	1.001	105,586.94	0.0969
				105,587	Btu/lb-mole
			Avg mol wt:	10.3	lb/lb-mole
			Density:	47.7	lbs/ft^3
			HHV:	10,221	Btu/lb

560.5°F and the second methane preheater operating at 1,142°F.

Results

Five steam-to-carbon ratios were tested —1:9, 2:2, 2:7, 3:2 and 3:7. Table 1 indicates the predicted water-gas shift conversions (*xm*).

Methane conversion increased, as expected, with higher ratios. However, methane conversion above 2.7 was nominal. Greater ratios diverted additional steam to the HYCO reaction, which increased the condensate recycle burden. The increased methane conversion at higher steam/carbon ratios did not offset the resulting loss of salable contract steam at our arbitrary 30-ton/h fuel limit.

Product flows are often sensitive to small changes in feedrates or other boundary conditions. Model identification of these break points early on can lead to better-recommended prototypical operating points.

When fuel heat content is not available, as in this example, it can be estimated from the chemical composition of the fuel components using traditional thermodynamic relationships. Use a suitable spreadsheet for calculating model fuel composition, as in our rubber blending computation of Table 2.

The heat content for tire-grade rubber is approximately 15,500 Btu/lb, which compares favorably with our estimated 15,640 Btu/lb.

Using the literature

Emissions data on SO_2 and NOx may be found in the professional literature. In our example, we set furnace primary air in our HYCO-methanol model process to the same 18% excess air conditions reported in the literature [*5*] to see if our NOx emissions would be comparable to a one-million-Btu/h pilot waste combustor.

Model results ranged from 269 ppm to a low of 178 ppm, denoted by the red squares in Figure 4. The Model NOx results obtained as a function of temperature also appear in red. Predicted emission data correlate well with previous literature pilot studies.

Calculated SO_2 levels for the model ranged from 24.5 to 74.08 ppm for the blended fuel tests. In the 1,600°F range, the model predicted SO_2 was 88.32 ppm. The literature [*5*] reports a level of 82 to 91 ppm for the two combustors tested at 1,550°F–1,600°F.

Model operation between 1,500°F and 1,600°F with 18% excess air matches the literature claim for control of NOx and good absorption of SO_2.

Calculated data that are close to literature values suggest the model material and energy balance relationships are reasonably accurate and representative. Proper directional trends in any model are essential.

Economics

Green projects are capital intensive and can take years for investment recovery. As government regulations continue to play an increased role in national economies, new energy sources are needed to sustain growth. There is a vast untapped reservoir of man made waste, lying in the ground, that may provide the solution to the nation's energy appetite.

A 2010 study [*1*] has found that, in comparing emissions from landfills versus municipal waste combustion using the U.S. Environmental Protection Agency's life cycle assessment (LCA) model for the range and scenarios evaluated, waste combustion outperforms land filling in terms of greenhouse gas emissions regardless of landfill gas-management techniques.

Better methods are needed to evaluate alternative energy sources and processes that can increase competitiveness in a global market. A good process model can predict unit prof-

itability under changing market and energy conditions.

A good rule of thumb is to begin a profitability study at the lowest set of process conditions attainable and then work upwards until a positive result can be obtained. Projects that require extreme conditions to give a positive return aren't worth the time involved. If it's profitable under minimum conditions, it's likely to be profitable throughout. It's a handy means for eliminating less-promising projects.

Most model packages permit data export directly into a personal spreadsheet already containing your project cost macros, which greatly facilitates economic analysis.

Using the model

EPA solid waste heating values [2] ranging from 5,040 to 5,865 Btu/lb were model tested to determine the potential profitability of the example synthetic fuel from waste process.

Model tests utilize the heat content of EPA landfill fuels up until 2005 (the year the EPA data tabulation ends), as indicated in Figure 6. Although greater temperatures than 1,600°F increase yield, they also increase emissions. Values above 1,900°F cause disassociation of $CaSO_4$ formed during sulfur dioxide removal from the fuel, and 2,000°F and above causes the NOx concentration to go up exponentially in the combustion reaction.

Figure 5 plots three projected steam margin lines for a low-heat content waste fuel (4,466 Btu/lb). The lowest line represents arbitrary steam pricing of $6.95 per 1,000 lb, based on a 2002 commercial contract. The model identified a 46% gross profit using this fuel. However, the model profit margin decreased with additional steam generation. Low fuel-heating values restrict steam generation and demonstrate the need for a higher energy content fuel.

The inflation-adjusted line demonstrated a satisfactory rate of return using the same fuel. If attainable, steam contract pricing should be set at a rate that helps reduce pay out.

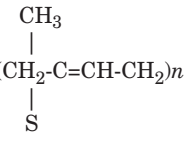
Fuel blending

Table 3 indicates a typical spreadsheet calculation that develops fuel energy content for the simulation. Heating value is based on the standard heats of combustion for the elements and blend composition.

A solid waste heating value of 5,865 Btu/lb was selected for 2005 [2] from EPA's 1989-2005 Solid Waste Heat Content chart to represent the model fuel base. The model fuel-base composition matches the EPA determined heating value.

The base heating value is EPA's 2005 [2] reported land-waste heat content to which scrap tire rubber was added.

Shown below is the chemical composition of tire-grade rubber:



Scrap tires are assumed to contain high moisture.

The model-blended fuel contains 2.38% sulfur, 14.67% moisture and has an ash content of 6.41% as shown in Table 3.

The mix is a simple ratio. For carbon content, the 2011 blend is:

C: = 0.5 * 0.48 + 0.5 * 0.5797
= 0.5297

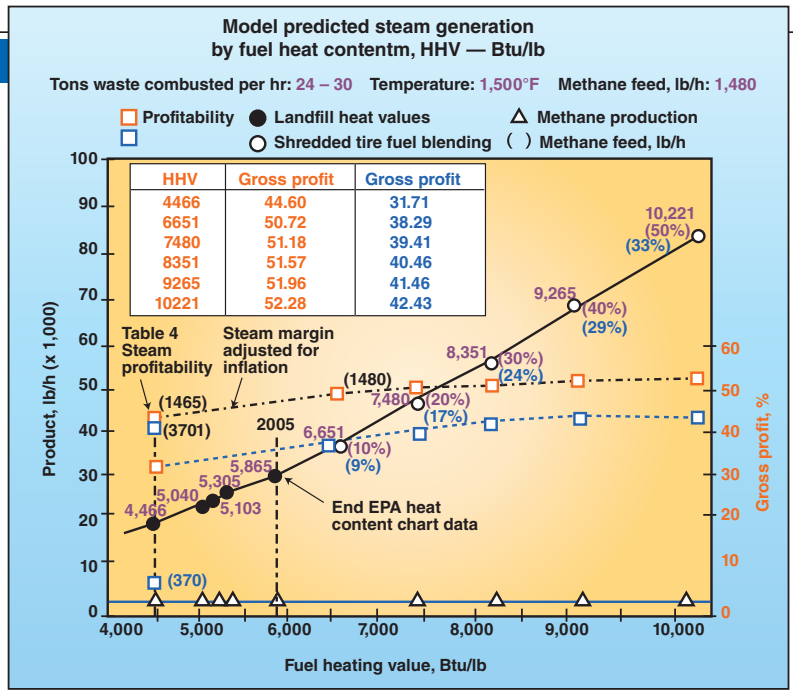


FIGURE 6. The model-predicted steam generation by fuel heat content (HHV-Btu/lb) suggests the best steam and methanol generation production points as a function of fuel heat content and a 30-ton/h fuel limit. The model-calculated product quantities at 1,500°F are converted into profit margins (curved dashed lines) help the engineer assess project viability (Source: Heat Content from Municipal Waste in the U.S., http://www.epa.gov/msw/msw99.htm)

Combustion

Add new fuel compositions and the updated heating value to the Furnace segment of the model, based on blending computations:

Calculate the fuel fed to the furnace at mid-range conveyor belt speed, '*S*' as a function of belt width '*w*' and fuel density '*d*':

fuel = *S* (ft/h) * *w* (ft^2 wide) * *d* (lb/ft^3)

Correct the blended fuel heating value (*Lhv*) for the energy lost from fuel moisture and hydrogen content.

The heating values of Figure 6 were determined by fuel blending. Calculated heat content appears next to each point with blend composition below in parenthesis. The dashed lines represent the model-predicted pre-tax profits, adjusted for inflation. The upper dashed line represents 30 tons per hour fuel consumption. The lower dashed line demonstrates the combined effect of 20% less throughput and a $3.56/ton fuel increase, resulting in a 10% profitability loss.

Fuel moisture for the tests ran between 13% and 16%, depending on blend composition.

Methanol production remained near maximum at 8,760 gal/d throughout the tests. But at 1,600°F, there was a 0.9% increase in methanol output.

The upper dashed line represents the best model-predicted pre-tax profits, adjusted for inflation. There is a noticeable slope change in the curve at 7,480 Btu/lb, suggesting that lower heat content will be insufficient for profitable steam production.

Capital costs

A feasibility estimate of the modeled process capitalized equipment, exclusive of environmental permits indicates a cost of $108,479,360 U.S. dollars as of March 31, 2011 [*3*]. This includes the cost of site excavation, buildings, parking, concrete, steel, construction labor, process equipment, installation, piping, distributed control (DCS), instrumentation, pneumatic valves, and administrative costs, including a 10% contingency. Taxes and interest charges were not considered.

The process equipment that is depreciated (but not limited to) includes electronics, instrumentation, vessels, motors and vehicles. The total depreciable sum is $35,782,083.

Assuming a 10% salvage value for the process equipment and a 40-year useful plant life, the annual straight-line depreciation is:

$$S.L. = \frac{\$35,782,083 - 3,578,208}{40} = \$805,097 / yr \quad (3)$$

For 30 ton/h of fuel consumed and a 50% fuel blend (10,221 Btu/lb), methanol production is:

$$438 gal/h \times 20 h/d \times \$1.00/gal = \$8,760/d \quad (4)$$

The predicted steam generation gross profit is:

$$\$82,336 lb/h \times \$8.58/1,000 lb \times 20 h/d = \$14,129/d \quad (5)$$

Annual revenue is: ($14,129 + $8,760) x 313 working d/y = $7,164,257.

The predicted pay out period, assuming no interest charges:

$$\frac{\$108,479,360}{\$805,097 + \$7,164,257} = 13.61 years \quad (6)$$

Pay out rises to 16.9 years at 20% less throughput and a $3.56/ton fuel increase.

Scrap steel sales from the tire blend were not used to calculate the pay out in our example. If the scrap metal composition for a green project is unknown, EPA recycling data [*6*] can provide a workable estimate of glass, metals and other salvageable materials in municipal waste. Resale of these commodities can reduce fuel production costs, improving overall economics.

Salable scrap from solid waste often can amount to tons/d. So salvaging item 'A' for example, produces '*tons/d*' x '*operating d/yr*' x '*$/ton*' = '*$A/yr*' of additional revenue. Assuming, fuel production costs are '*$C/yr*':

Adjusted fuel cost:

$$\frac{\$C/yr - \$A/yr}{Total\ tons/yr} = \$/ton \quad (7)$$

The example process has potential given the fuel tests were restricted to 30 tons/h maximum of blended waste. It is reasonable to expect that much higher steam outputs are attainable since the blended heating values are comparable to coal.

Payout is acceptable for the green project and it shows promise, demonstrating profitability under minimum throughputs.

The engineer should consider further investigations of this process based on model predictions, with an eye towards improving conversion and plant throughput for enhanced profitability and better pay out.

Higher methanol and steam pricing is not recommended as a means towards this end as market factors play an increased roll in product prices.

Conclusions

Dynamic models are useful tools to evaluate any process that can be represented mathematically. Engineers can use them to not only emulate a given process but to test competing control strategies, trend cost variables, and identify and implement process improvements. Modeling a process provides the best means of culling out the most promising projects from the pack.

Dynamic models also give engineers a development tool for determining the suitability of solid waste compositions as a fuel source for a particular process. As demonstrated here, engineered fuel pellets produced from municipal waste sources can provide a sustainable and reliable fuel, whose use can help to reduce dependence on petroleum-derived fuels well into the future. ■

Edited by Suzanne Shelley

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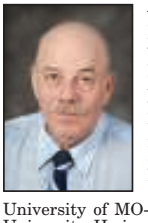

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Ken Dunwoody (Email: Kdunwoody2@aol.com) prior to his retirement, chairman and chief operating officer of RCR Systems, Inc., where he and the firm's general partners developed the RCR solid waste handling system prototype. His firm holds five patents in waste-separation machinery. Prior to that, Dunwoody was general manager of the glass manufacturing division in charge of production at Coors Container. He holds a B.S. in business administration and Associate degrees in digital electronics and industrial management the Univ. of Colorado and the Denver Technical Institute.

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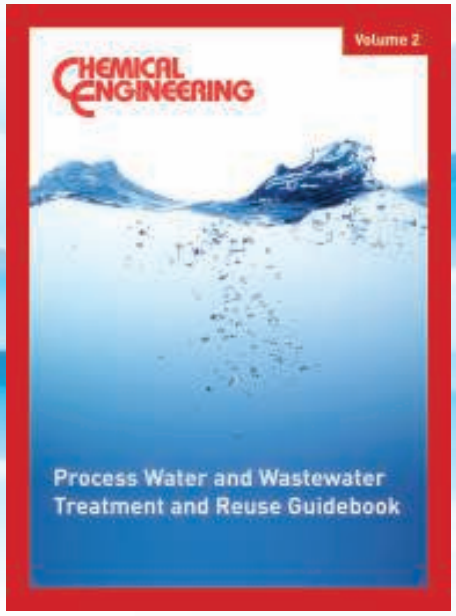

This guidebook contains how-to engineering articles formerly published in *Chemical Engineering*. The articles in Volume 2 provide practical engineering recommendations for process operators faced with the challenge of treating inlet water for process use, and treating industrial wastewater to make it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

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

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Overpressure Protection: Consider Low Temperature Effects in Design

Understanding the inherent limitations of current overpressure-protection analyses is key to developing a more robust heuristic

Aubry Shackelford
Inglenook Engineering

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In designing and sizing relief-device and effluent-handling systems, one commonly overlooked aspect of the performance is examining the potential for low temperatures that can cause the components of the system to reach temperatures below their respective, minimum-design metal temperatures (MDMT), which may result in brittle fracture with subsequent loss of containment. This article points out limitations of the typical overpressure-protection-analysis philosophy, discusses common sources of low temperatures for further investigation, and addresses possible design remedies for MDMT concerns.

The primary objectives of a process engineering evaluation of an effluent handling system (such as a flare system) include ensuring that operation of the pressure relief devices discharging into the collection system (flare headers, for example) is not adversely affected; and that the effluent handling equipment are properly designed to perform safely. The results of an overpressure-protection design are the primary input for this engineering evaluation; however, there are several potential gaps in the ability of these data to identify situations in which the MDMT may be exceeded.

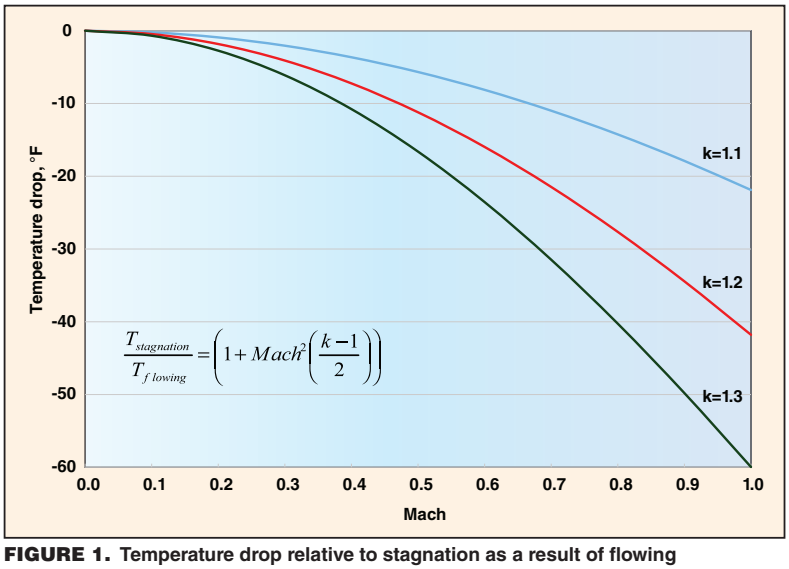


FIGURE 1. Temperature drop relative to stagnation as a result of flowing

Current-practice limitations

Common practices for pressure relief and effluent handling are found in numerous references [*1–5*]. The processes for estimating a discharge temperature and performing the outlet pressure-drop calculations in the pressure-relief-device discharge piping are limited in their ability to accurately predict flowing temperatures for many situations.

First, the discharge calculations are quite often only performed for the controlling contingency for which the pressure relief device was sized, which does not necessarily represent the most likely cause of overpressure or the cause resulting in the lowest discharge temperatures.

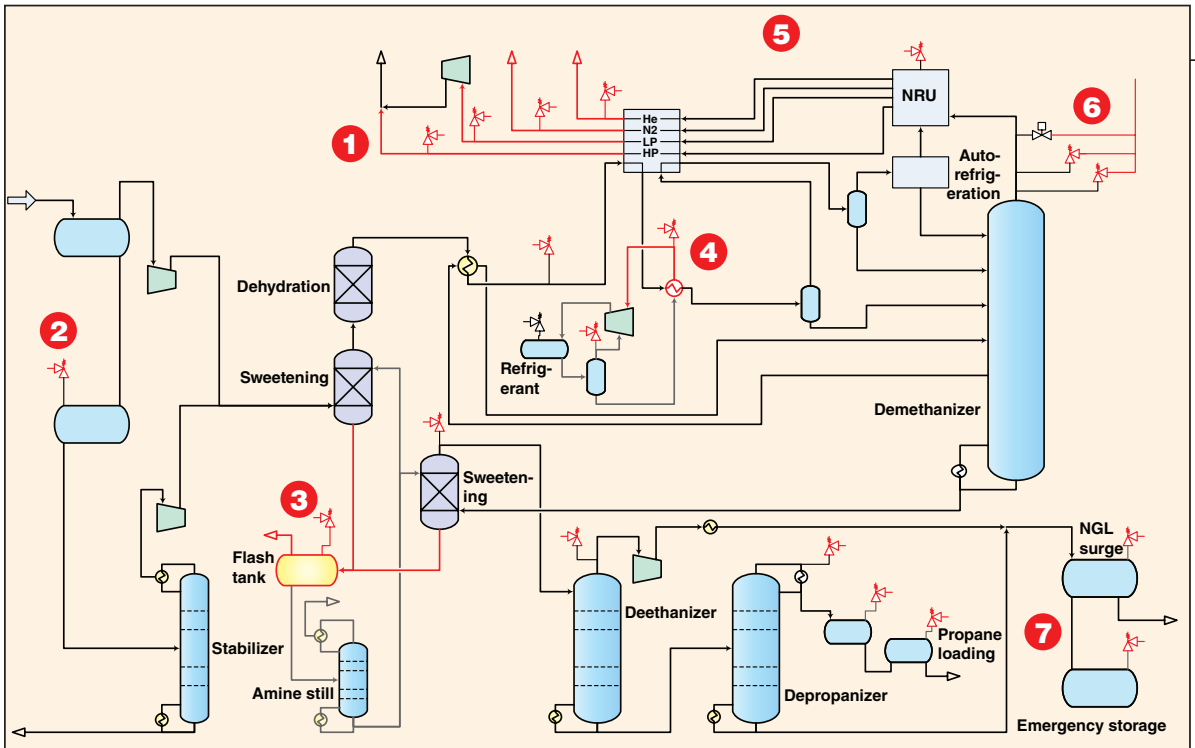
Second, the outlet pressure-drop calculations for individual pressure relief valves consider the *outlet* discharge piping and potentially exclude the remaining, downstream piping system. This practice can result in a temperature discontinuity between the calculated discharge temperature for the individual relief device and that calculated for the same section of piping considering the entire downstream piping system using an effluent-handling hydraulic model.

Third, the temperature estimates are typically made for isothermal pressure-drop equations and do not account for effects like retrograde condensation.

Fourth, some simplifications of the calculations that are used for the purposes of estimating the outlet pressure drop do not represent flashing effects (for example, highly subcooled flashing liquids are often choked at the bubblepoint; therefore, the sizing of the valve may assume the backpressure is at the bubblepoint).

Finally, the temperature estimates tend to be based on either relieving temperatures or isenthalpic flashes from relief conditions, which do not account for kinetic energy effects. These effects can be substantial if the developed velocity in the outlet piping is high and can be compounded when there are multiple relief devices discharging simultaneously into a collection system, or when large diameter differences exist between the tail-pipe and the main effluent header.

Temperature drop. Figure 1 shows the temperature drop from the stagna-



1. Process upsets in the NRU can cause low flowing temperatures to propagate downstream to after the gas/gas exchanger, which is typically designed based on normal operating temperatures
2. Relief of unstabilized condensate, a flashing liquid
3. Breakthrough of high pressure gas or flashing liquid into the flash tank
4. Tube rupture in the chillers cause relief of expanded gas that starts cold and is cooled further by JT effects
5. Valve specifications for appropriate MDMT are common issues
6. Common discharge lines can cause increased velocities, further reducing flowing temperatures. Also depressuring is an isentropic process that results in low flowing temperatures
7. Potential relief of flashing volatile liquids that can cool significantly based on flashing

FIGURE 2. Typical schematic of NGL processing facility showing common areas of potential MDMT issues

tion temperature ($T_{stagnation}$) caused by the kinetic energy developed during adiabatic compressible flow of an ideal gas as a function of the Mach number for ideal gases having different ideal-gas specific-heat ratios (k) (see Ref. 6, Equation 6–128). For the purposes of illustrating the temperature drop, a stagnation temperature of 0°F (460R) was chosen.

It is useful to note that while a stagnation temperature of 0°F seems unlikely for many cases, this stagnation temperature is established after the fluid has been relieved into the collection system (in other words, after the isentropic process of flowing through the pressure-relief-valve nozzle and the subsequent adiabatic process of expanding from the nozzle throat to the total backpressure that results in Joule-Thompson (JT) cooling, both of which can result in significantly lower stagnation temperatures of the fluid entering into the discharge piping).

Additional limitations. Additional gaps in the overpressure protection analysis include the common practice of not considering the potential for pressure relief valves to leak, or the effects of other inputs to the effluent handling system (such as pressure control valves, depressuring valves, pump seals and manual purge valves). A leaking pressure-relief valve is typically considered an operational and mechanical issue, not a cause of overpressure that needs to be evaluated for the sizing of the pressure relief valve or for the effects on the downstream collection system; however, many of us in the warm Gulf Coast region of the U.S. recognize an ice-covering as indicative of a leaking valve, and the fluids used in the evaluation of the pressure-relief-device sizing may not be representative of the normal process fluid (for example, the external fire case, which is a common design basis).

Pressure control valves may also be called upon to "relieve" fluids, yet are commonly not accounted for in overpressure protection studies based on the desire to not include the positive response of control systems in preventing overpressure. In actual situations, the basic process-control systems are expected to function as intended, and thus represent a more likely source of fluid input to the collection system.

In addition, these control valves are not necessarily sized to handle the full flow of an overpressure scenario, resulting in flow from both the control valve and the pressure relief valve, thereby exacerbating velocity effects.

Finally, depressuring is a dynamic process, releasing fluids of different pressures and temperatures as a function of time. Considering the most likely behavior of a depressuring system to be an isentropic expansion of the residing fluid, the inlet fluid temperatures can drop significantly as the depressuring progresses.

Low temperatures

While the potential for low flowing temperatures falling below the MDMT exists in a variety of processing facilities, the issue is especially apparent in natural-gas processing facilities where high pressure, low temperature, low-molecular-weight gases and volatile liquids are present.

Design considerations. Based on recent evaluations of several natural-

gas processing facilities with ethane recovery capabilities, the authors have identified several common areas of concern that may provide a starting point for other gas processors' investigations into this aspect of collection system design, as well as for process piping. These areas include the following: multiple inputs (such as pressure relief devices or control valves) discharging into subheaders having diameters close in size to the individual discharge piping diameter; flashing liquid relief (unstablized condensate, natural gas liquids [NGL] or liquid propane); internal-boundary-failure cases (tube rupture, for example) in gas chillers; cryogenic drain operations (such as draining expander casing for maintenance); pressure-relief-device MDMT specifications not commensurate with discharge piping MDMT; and pressure relief devices or vents on the outlet of cryogenic cold-box sections where the normal process fluid is at elevated temperatures, yet during process upsets may experience significantly lower temperatures.

Figure 2 provides an overview of these common areas of concern related to low flowing temperatures. NGL and propane processing-and-storage equipment are examples of commonly overlooked systems that can achieve low flowing-discharge temperatures. These equipment usually have pressure relief devices that are sized based on an external fire case, yet also have the potential for relieving the liquid either due to blocked discharges, leaking relief valves or depressuring.

Alternative solutions. While the design issues related to low flowing temperatures can be dealt with by specifying appropriate metallurgy, there are other alternatives for consideration. These alternatives can include identifying ways to eliminate the cause of overpressure in the first place (for example, prevention of overfilling of vessels), mitigation of relieving conditions causing the low temperature excursion via safety instrumented systems (SIS), performing mechanical stress analyses to establish a better estimate of the MDMT per ASME B31.3 (with replacement of components not covered by stress analysis as needed), adding supplemental fluid (such as gas or methanol) to raise the stagnation temperature, rerouting the discharge to a different location (such as to the atmosphere), or conducting Charpy testing on the piping in question to establish the actual MDMT.

For potentially leaking pressure-relief valves, the options also include recognizing the additional consequences in a risk-based inspection protocol, installing rupture disks, or adding skin thermocouples and low temperature alarms on the discharge piping to notify personnel of leakage before the MDMT is crossed.

Final analysis

In summary, established overpressure-protection-analysis philosophies are not well suited to identify possible material concerns as a result of process fluid flashing and depressuring. Relief-device and effluent-handling sizing conventions and simplified calculation methodologies limit the ability of the designer to recognize potential MDMT concerns. Understanding the inherent limitations of current overpressure-protection-analysis practice is key to developing a more robust overpressure protection analysis heuristic, which more fully recognizes the effects of low temperature flashing on material design.

It is the experience of the authors that modification of the typical overpressure-protection-analysis philosophy to identify and propose alternative solutions for conditions resulting in excursions beyond MDMT is prudent in promotion of enhanced facility process-safety management. ■

Edited by Dorothy Lozowski

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Note

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Working with the CSB After a Major Accident

When a serious accident occurs, the CSB may immediately investigate at the scene. Understanding the process helps companies prepare for such an investigation

Joseph Schreiber
Vorys, Sater, Seymour & Pease

After a serious accident at a chemical plant, petroleum refinery or other freestanding industrial facility, the U.S. Chemical Safety Board (CSB; www.csb.gov) may immediately initiate an investigation, often getting "in the air" while the emergency is still unfolding. The CSB team will consist of skilled accident investigators who are often accompanied by independent experts noted for their specialized knowledge of whatever systems or processes are to be investigated. They also arrive with legal authority — sometimes in the embodiment of accompanying federal marshals. All in all, the process is unlike anything you've ever experienced if your experience is limited to the U.S. Occupational Safety and Health Admin. (OSHA). This article aims to provide a sense of that process as well as some suggestions for managing it.

CSB agents come not with the power to levy fines but with a potentially much greater power: the power to shape the narrative of the accident, to frame the questions that define the cause of the accident and to establish fault; all of which is then neatly packaged in a report oftentimes including a dramatic reconstruction of the event, which may be admissible in the tort suit that is sure to follow any accident. Since the cost of a tort suit — in legal fees and settlement costs — may far exceed any agency fines, a CSB investigation is a serious affair that may create significant risks if it is handled improperly.

As most chemical engineers are aware, the CSB is an independent federal agency charged with investigating industrial chemical accidents. The CSB staff includes chemical and mechanical engineers, industrial safety experts, and other specialists with experience in private and public sectors. It may hire someone with expertise in your particular product or process — perhaps even someone who has published articles about it in the scientific literature.

When thinking about the CSB the following analogy, though imperfect, may help: The CSB is to OSHA as the National Transportation Safety Board (NTSB) is to the Federal Aviation Administration (FAA). Both the CSB and NTSB are investigatory and advising bodies. They have no inherent power to fine. But, their recommendations are taken very seriously by both the government and by the legal system.

Process safety management

The CSB conducts a root cause analysis. Because the goal of the CSB is to prevent future accidents and because, philosophically, it believes most accidents are the result of systemic failures, the "root cause" will almost never be found to have been operator error or mechanical failure. CSB has stated on video that "catastrophic incidents...are never caused by a single operator flipping the wrong switch or one piece of equipment that malfunctions." It has stated privately during an investigation: "We're never going to tell you that the answer is to fire an incompetent employee. Either you hired someone incapable of doing a critical job or you hired someone competent and then failed to adequately train him. Either way, it was a failure of process safety management."

The CSB will also take the opportunity to investigate emergency response. A detailed investigation of emergency drills, accounting for personnel and host accident-investigation measures conducted by the company, is typical.

At the core of all CSB analyses is process safety management: how the company manages hazards mechanically; how employees are trained; how the company audits its operations to identify potential hazards; and, how the company communicates process changes and effectively trains employees regarding new processes. Perhaps most importantly, the CSB wants to see whether the company keeps abreast of industry best practices, including those recommended by the CSB itself.

Consequently, CSB will invariably find safety-management-system flaws, including inadequate training, as the root cause of any accident. The finding of system flaws, though unavoidable, is not the company's major worry. The major worry is the type of report the CSB will prepare and how the company will be portrayed in that report and in the public meetings that CSB conducts.

Reporting process

CSB will conduct a public, interim progress-report meeting. At that report meeting, which will be held in the town where the plant is located, CSB will present its initial findings and take questions from the public. The press may be present. When the final report is completed, CSB will hold another meeting, open to the public, and the board will vote on whether to accept the report.

CSB generally prepares three levels of reports. The first is simply a letter report with few details and a root cause determination. The second level is more in-depth, identifies the root cause and improvements that should be made, and is likely very similar to a report the company would do on its own. The third level of report contains a narrated video with a soundtrack, including both footage of the burning plant and virtual reality depictions of the accident process, the explosion and a mock-up of the carnage that occurred. This last level will include internal company documents showing safety deficiencies and unheeded warnings. Causation will be established. This type of video will be very persuasive evidence in the tort trials against the company. The company's reaction to CSB's investigation in large part determines the type of report written.

The investigation

A major consideration is what to do when the CSB arrives at a plant. CSB agents come unannounced. The first notice a plant manager will get of CSB's investigation will be a group of people who show up at the gate and pull on jackets with the CSB logo on the back, present badges, and may be accompanied by an armed federal marshal. The company should immediately do two things: (1) make a senior safety engineer available to CSB for the duration of the investigation; and (2) call the company's tort attorneys.

CSB and its outside experts will be professional, learned and tenacious. They cannot be stalled by being assigned to talk to a low level manager or hourly employee. They will want documents, safety videos, procedure manuals, proof that employees have read and signed the procedure manuals, and access to employees to conduct interviews. CSB has subpoena power and will use it.

The company's tort attorneys, both internal and external, should be called in immediately. CSB respects the attorney-client privilege. It also respects the internal investigation privilege. Both these privileges protect work done by attorneys to figure out what happened in the accident and also to prepare company witnesses for interviews with CSB. A company cannot hide any facts with lawyers. That isn't the point. The point is that work done by the company attorneys to find the root cause will be protected from Freedom Of Information Act requests from plaintiff attorneys and activist organizations.

Work done by the company to gather documents for CSB review will be appreciated. The CSB will also appreciate prepared witnesses who have given thought to what happened and why.

The company must develop the narrative of what happened and why. The narrative needs to be consistent among employees at different levels of the plant: from the laborers, maintenance workers and operators, engineers and managers. Frequently in factual investigations when people tell the truth, while the details of recollections are somewhat different due to different views of the event, a consistent narrative of what happened and why will emerge. The company's lawyers must work very quickly to gather facts, interview witnesses and workers, and develop the narrative. Finding out the narrative, making sure it is consistent and identifying anyone who may be lying for whatever reason, and making sure they do not lie to the CSB — out of a misguided sense of self preservation or out of malice to the company — is of paramount importance.

CSB will likely work with the company at finding the root cause of the accident. If CSB feels it is being lied to or stonewalled, its agents and experts will find the truth anyway and the resulting language used to describe the root cause and company failures will be much more severe.

The company's narrative must focus on process safety management. If there was a breakdown in process safety management, even if it was employee error or equipment failure, the process should be examined. If an employee failed, the CSB will not find and report that the employee was at fault. The company should discuss improving employee training. If it was a product that failed, the company should discuss maintenance and more-frequent safety reviews and audits.

There is an inclination by companies to refuse to admit any failures or deficiencies. However, as stated earlier, CSB will never find that an individual employee is to blame nor will it find that a single piece of equipment failed. If it is presented with a narrative from the company, or worse yet, a publicly released report by the company blaming a single operator error or single equipment failure, CSB will likely respond by finding and reporting major safety-system flaws. CSB's report will then be made public and become both an exhibit in the coming trial and provide a roadmap for the plaintiffs' lawyers. Such a situation, where the company blames an operator's error, has drawn strong rebukes and narrated, soundtrack-accompanied video reports from CSB identifying the process failures that led to the employee's final action, which may have triggered the accident. Juries and the public are likely to excoriate a company that blames a single employee when the CSB points out systemic company failures. Blaming a single employee's error, especially in a company report, will end badly for the company.

In noting areas of process safety management that can be improved, and admitting that things did not go perfectly — which would not be a stretch as a major accident has occurred — it can be hoped that CSB will accept the recommendation the company makes for improving the process safety management. In this regard, it is much like a college sports program self-reporting to the NCAA (National Collegiate Athletic Assoc.) and self-imposing penalties hoping to avoid a finding of lack of institutional control.

When CSB finishes its full report, it will usually show the report to the company and allow comment. This is not the time for the company to expect to make substantive changes. CSB will change patent errors; things such as employee names being misspelled or the wrong person being quoted. If the company waits until this stage in the investigation to present its narrative to CSB, it will be far too late to influence the outcome of the investigation. Instead, as mentioned earlier, the company should work immediately to gather and share information and documents with CSB, interview and prepare employees for interviews by CSB (which are frequently performed tag-team style) and develop a narrative of the cause of the accident focusing on safety process systems, and self-suggesting improvements.

Safety management is key

It may seem too obvious to say, but a company's actions before an accident are just as important as its response to the accident. Accidents can occur even in the best run companies. An ongoing focus on safety process systems, with regular audits of the systems and processes, should become a regular job of the plant safety management. In particular, a few areas should be monitored regularly. First, the company needs to review and update disaster accountability. This is literally accounting for workers after a major accident. The process for accounting for each and every employee needs to be monitored. Systems in which employees have to leave through a designated gate should be reformed because they are unrealistic. Likewise, antiquated systems where employees sign in manually after an accident are likely to be frowned upon. An automatic badge reader system should be implemented. After an accident, CSB will likely spend a lot of time reviewing the employee accountability system if it is not automated.

Second, companies should review their safety training materials. CSB regularly produces safety training videos. CSB is rightfully proud of its videos and encourages companies to use them. Companies should do so. They should also document both employee participation in the training sessions and understanding of the training.

Third, companies should review and implement CSB's proposed safety regulations. CSB recommends safety regulations to EPA, OSHA and Congress as part of its duties. These are published. Companies should not wait until after the recommendations become law to implement them. If a recommendation has been published by CSB and not followed by a company, but the recommendation could have helped avoid the accident, the failure to follow the safety procedure will almost certainly be found by CSB to be a root cause of the accident. Such a root cause finding may even be used to support a jury finding of conscious indifference and malice on the part of the company. The recommendations give both notice of the potential harm and a solution.

Put simply, common sense prevails. CSB is a powerful agency inside the federal government. Its power flows from its expertise, tenacity, and investigative abilities. It will investigate after a major accident. Its conclusions will carry weight in courts of law and in the court of public opinion. A company that quickly investigates the cause of the accident, focusing on processes and not blaming single people or single pieces of equipment, prepares its employees to deal with CSB, and works with CSB, will be better able to focus the narrative and avoid harsh results in the inevitable tort trial. ■

Edited by Dorothy Lozowski

Author

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Design practices committee

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

Where do middle boilers go? If you answered, "Nobody knows", then you're wrong. FRI's Design Practices Committee (DPC) knows — and they're willing to share.

The DPC was formed in 1975. It originally contained just six members. Neil Yeoman was one of the original members. He still participates on the DPC today — as a consultant. Dan Summers, of Sulzer Chemtech, is presently the chairman of the DPC. It includes distillation experts from the world's biggest users of distillation and absorption. A DPC meeting attendees roster reads like a Who's Who in Distillation list: Jeffrey Bell, Ed Grave, Henry Kister, Todd Marut, Paul Morehead, Ron Olsson, Joe Parker, Keith Whitt, Larry Wilder, Simon Xu, Attilio Praderio, Brad Fleming and Randy Hollowell. John Farone and Doug Bouck consult.

Generally, the DPC studies all of the aspects of distillation that are not (usually) addressed by the FRI Stillwater staff. For example, the DPC addresses scaleup, troubleshooting, gamma scanning, fouling, instrumentation, small-diameter columns, startups, shutdowns, mist elimination, inspections, middle boilers and transitions. Transitions include feeds, flashing feeds, sidedraws, surge volumes, reboilers and condensers. Regarding trays, the DPC studies weirs, blanking, gasketing, fabrication, assembly and mechanical strength. Regarding packing, the DPC studies installation, removal, hold-down grids and support plates. Very recently, the DPC completed the largest project in its history — a compilation of information regarding packing distributors, including distributor testing.

Ultimately, the DPC work product ends up in Volume 5 of the FRI Handbooks. In some most important cases, the work product goes public. In the July 2007 issue, this magazine published "Causes and Prevention of Packing Fires." A photograph of the authors, the DPC members, was presented on p. 42. That article discussed how hot work inside columns that contain structured packings can ignite the packings. Such ignitions have occurred too often in distillation history. Once the packing starts burning, suppression is very difficult. Personally, subsequent to the issuance of that article, I have not heard of any new incidents.

More recently, in the January 2012 *Chem. Eng.* issue, the DPC authored "Reboiler Circuits for Trayed Columns." That article summarized reboiler options for the bottoms of distillation columns. Included were the advantages and disadvantages of vertical thermosyphon, horizontal thermosyphon, kettle, forced circulation and internal reboilers. Many different piping configurations were compared.

Sometimes a distillation column fails — or even burns down. Sometimes a reboiler limits a column's throughput. There are so many ways whereby distillation columns can fail, that it is almost surprising that the vast majority of them purr incessantly. When a column fails, many people suffer, including the engineers, the plant owners and the public (via shorter local supplies and higher prices). The FRI Design Practices Committee members strive to reduce global column shortfalls. They are herein commended, especially Neil Yeoman and Dan Summers. ■

Mike Resetarits
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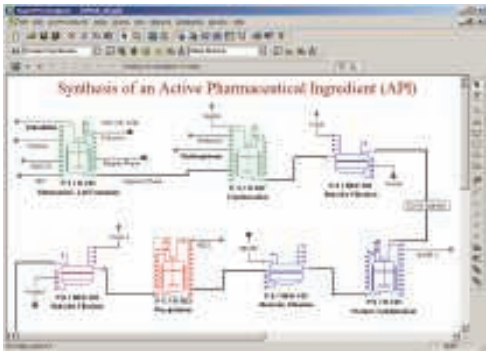

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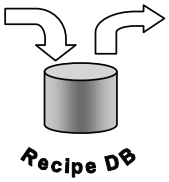

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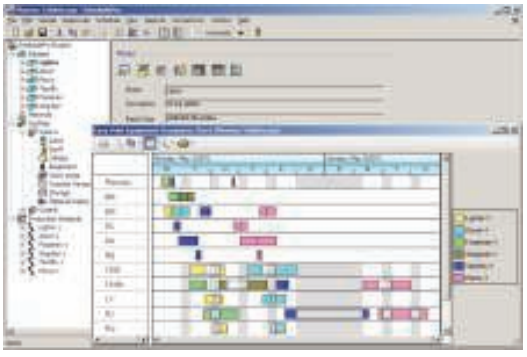

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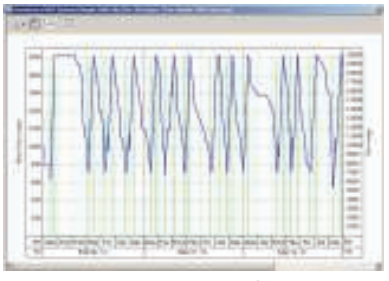

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WHO'S WHO

Lachowska-Keane

Hahn

Banerjee

Morse

Walker

Albermarle (Baton Rouge, La.) names *John Steitz* president and COO.

Joanna Lachowska-Keane becomes the manager of the engineering-and-construction company **Sener Poland** (Warsaw).

Lonza (Basel, Switzerland), a producer of biopharmaceuticals, names *Richard Ridinger* CEO.

Blacoh Fluid Control (Riverside, Calif.) names *Terri Simmons* global customer service manager, and *Bill Bendel* technical sales manager.

Greg Hahn is named CEO of **Toll Solutions, LLC**, a division of **InChem Corp.** (Rock Hill, S.C.) that specializes in toll and custom dispersion, emulsion and blending for the CPI.

Prith Banerjee becomes chief technology officer of **ABB** (Zurich, Switzerland).

David Morse, executive vice president and chief technology officer at **Corning, Inc.** (Midland, Mich.) joins the board of directors of Dow Corning Corp.

AGY (Aiken, S.C.), an advanced materials solutions company, names *Drew Walker* president.

Engineering and construction company **Wood Group Mustang** (Houston, Tex.) names *Bill Vicary* director of business development for the process plants and industrial business unit, based in Greenville, S.C. ■

Suzanne Shelley

BUSINESS NEWS

PLANT WATCH

Solvay to build bio-based epichlorohydrin plant in China

June 11, 2012 — Solvay S.A. (Brussels, Belgium; www.solvay.com) says its Thai affiliate Vinythai will build an epichlorohydrin plant in Taixing, China. The plant, with an initial capacity of 100,000 ton/yr, will cost €155 million and will start up in the second half of 2014. It will use Solvay's proprietary Epicerol technology, and its feedstock will be natural glycerin obtained as a byproduct of biodiesel manufacture. Compared to the conventional propylene-based process, an Epicerol plant is cheaper to build, emits 60% less CO_2, and produces just one-eighth of the chlorinated by-products, Solvay says. Vinythai started up its first 100,000 ton/yr Epicerol epichlorohydrin unit in Thailand in February 2012. The new plant will make Vinythai the second-largest epichlorohydrin producer in Asia.

Indian firms choose Axens' AlphaButol 1-butene technology

June 11, 2012 — Indian Oil Corp. Ltd (IOCL), India's largest commercial enterprise, has chosen AlphaButol technology from Axens (Rueil-Malmaison, France; www.axens.net) to produce high-purity 1-butene by ethylene dimerization. A 20,000 ton/yr Alphabutol unit will be built at IOCL's Panipat complex in the state of Haryana. Panipat is IOCL's most modern refinery and the site of India's largest naphtha cracker. The IOCL unit is one of three recent AlphaButol licenses in India. Another 20,000 ton/yr AlphaButol unit, announced May 29, 2012, will be installed at the petrochemical complex of natural gas producer GAIL (India) Ltd. at Pata. AlphaButol technology uses homogeneous catalysis and has a low investment cost, Axens says.

Cabot completes expansion at Massachusetts inkjet pigment facility

June 11, 2012 — Cabot Corp. (Boston, Mass.; www.cabotcorp.com), the world's largest manufacturer of aqueous inkjet pigment dispersions, has completed a $10 million expansion at its Haverhill, Mass., inkjet facility. The project doubles Cabot's capacity for its CAB-O-JET small-molecule color and polymer-attached pigment dispersion lines. Work began in summer 2011 and was officially completed at the end of March 2012, after more than 31,000 contractor hours with no recordable injuries. The inkjet market for commercial printing will more than double in the next three years, Cabot says. Applications include credit card statements, personalized direct mail, and especially "print on demand" books,

TWD Technologies to engineer Canada's largest biodiesel plant

June 6, 2012 — TWD Technologies (Burlington, Ontario, Canada; www.twdtechnologies.com) has been selected by Great Lakes Biodiesel (GLB) to provide engineering, procurement and construction management (EPCM) for Canada's largest biodiesel plant. Scheduled to be operational by the third quarter of 2012, the plant in Welland, Ontario, will have a capacity of 170 million L/yr. Its feedstock will be Canadian vegetable oils such as canola and soybean.

MHI wins FEED contract for Hydrogen Energy California IGCC project

May 31, 2012 — Mitsubishi Heavy Industries, Ltd. (MHI; Tokyo; www.mhi.co.jp) will provide front-end engineering and design (FEED) services for the gasifier and power island of the Hydrogen Energy California (HECA) project near Bakersfield, Calif. Funded in part by the U.S. Dept. of Energy (DOE; Washington, D.C.; www.energy.gov), HECA is an integrated gasification combined-cycle (IGCC) power generation plant (400 MW_e) with a 2,500 ton/d fertilizer plant utilizing syngas as feedstock. After all permits are received and all funding is in place, the project could be one of the world's first commercial-scale IGCC power plants with 90% or greater carbon capture and storage (CCS) capability. The recovered CO_2 will be used in fertilizer production and for enhanced oil recovery (EOR). SCS Energy LLC (Concord, Mass.; www.scsenergyllc.com) is developing the HECA project.

Outotec awarded titanium mega-smelter project in Saudi Arabia

May 31, 2012 — Outotec Oyj (Espoo, Finland; www.outotec.com) has agreed with Cristal Global, the world's second-largest titanium dioxide pigment producer, on the design and delivery of technology and services for new ilmenite smelting facilities in Jazan Economic City, Saudi Arabia, as well as turnkey installation and construction of the plant. The overall contract value exceeds €350 million over three years. The plant will produce 500,000 m.t./yr of titanium dioxide slag and 235,000 m.t./yr of high-purity pig iron when it starts up in 2014, with an option to double capacity in the future. Ilmenite, an iron-titanium oxide, is used to produce titanium and titanium dioxide. Cristal Global has ilmenite mines in Australia and pigment plants in the USA, Europe and Saudi Arabia.

MERGERS AND ACQUISITIONS

Altana takes over isocyanurate business from Chinese firm

June 12, 2012 — Elantas Electrical Insulation, a division of specialty chemicals group Altana AG (Wesel, Germany; www.altana.de), has agreed to buy the tris-2-hydroxyethyl isocyanurate (THEIC) business of Chinese manufacturer Changzhou Lantian Ruiqi Chemical Co., Ltd. The deal includes production facilities in Changzhou, plus technology and employees, and is expected to be completed in the third quarter of 2012. Elantas plans to rename the business Elantas Changzhou Ltd., expanding capacity and continuing to supply Lantian's existing customers. THEIC is used to coat copper wire.

Intelligrated to be acquired by European investment company

June 8, 2012 — Automated material handling specialist Intelligrated, Inc. (Mason, Ohio; www.intelligrated.com) is to be acquired by a holding company owned by European private equity firm Permira in a deal valued at over $500 million. Intelligrated's management, led by founders Chris Cole and Jim McCarthy, will continue in place with a significant stake in the company. The transaction is expected to close in the third quarter of 2012. Intelligrated has operations in the U.S., Canada, Mexico and Brazil. Products include conveyors, sorting systems, palletizers, robotics, order fulfillment systems, warehouse control software and machine controls. Permira has two U.S. offices and has previously invested in several U.S. businesses.

Bürkert acquires Swiss pharmaceutical specialist BBS Systems

June 7, 2012 — Fluid technology specialist Bürkert GmbH (Ingelfingen, Germany; www.buerkert.de) has completed its acquisition of BBS Systems AG (Wil, Switzerland) after five years of cooperation. BBS Systems was founded in 1993 and specializes in components and system solutions for biotech and pharmaceutical plant engineering. The integration of BBS Systems into the Bürkert Group "is a logical step in our growth-oriented strategy in the hygienic processing segment," said Heribert Rohrbeck, managing director of Bürkert. ■

Charles Butcher

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FOR MORE ECONOMIC INDICATORS, SEE NEXT PAGE

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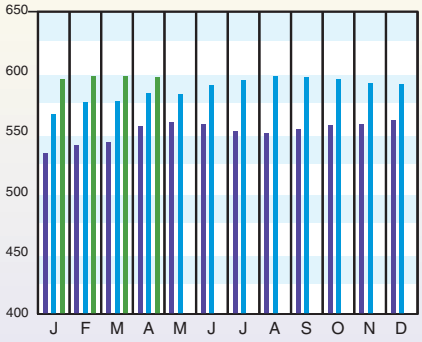
CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957-59 = 100)	Apr.'12 Prelim.	Mar.'12 Final	Apr.'11 Final
***CE* Index**	596.0	596.1	582.3
Equipment	730.2	729.9	708.0
Heat exchangers & tanks	686.9	686.6	671.4
Process machinery	680.7	680.7	665.3
Pipe, valves & fittings	935.7	934.8	867.9
Process instruments	430.8	433.9	443.7
Pumps & compressors	921.8	922.2	904.7
Electrical equipment	514.9	513.6	502.6
Structural supports & misc	774.2	772.1	752.8
Construction labor	320.9	323.0	325.8
Buildings	527.2	526.2	517.1
Engineering & supervision	328.4	327.8	333.6

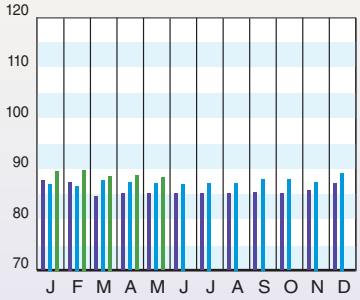
Annual Index:
2004 = 444.2
2005 = 468.2
2006 = 499.6
2007 = 525.4
2008 = 575.4
2009 = 521.9
2010 = 550.8
2011 = 585.7



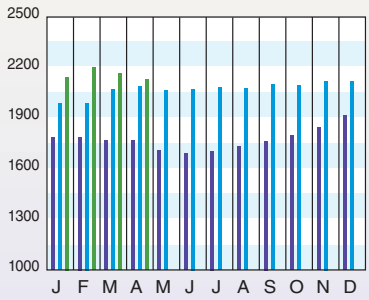
CURRENT BUSINESS INDICATORS

	LATEST		PREVIOUS		YEAR AGO	
CPI output index (2007 = 100)	May.'12 =	88.3	Apr.'12 =	88.7	Mar.'12 = 88.6	May.'11 = 87.1
CPI value of output, $ billions	Apr.'12 =	2,128.4	Mar.'12 =	2,167.3	Feb.'12 = 2,199.3	Apr.'11 = 2,089.4
CPI operating rate, %	May.'12 =	76.3	Apr.'12 =	76.7	Mar.'12 = 76.6	May.'11 = 75.1
Producer prices, industrial chemicals (1982 = 100)	May.'12 =	324.4	Apr.'12 =	329.6	Mar.'12 = 329.5	May.'11 = 341.8
Industrial Production in Manufacturing (2007=100)	May.'12 =	94.3	Apr.'12 =	94.7	Mar.'12 = 94.0	May.'11 = 89.7
Hourly earnings index, chemical & allied products (1992 = 100)	May.'12 =	157.5	Apr.'12 =	160.7	Mar.'12 = 157.3	May.'11 = 156.7
Productivity index, chemicals & allied products (1992 = 100)	May.'12 =	104.9	Apr.'12 =	104.7	Mar.'12 = 105.3	May.'11 = 106.3

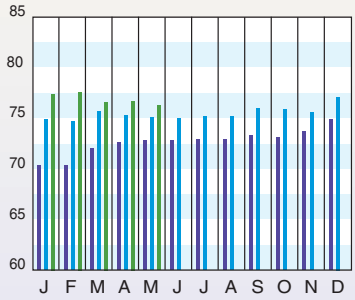
CPI OUTPUT INDEX (2007 = 100)



CPI OUTPUT VALUE ($ BILLIONS)



CPI OPERATING RATE (%)



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

CURRENT TRENDS

Capital equipment prices, as reflected in the *CE* Plant Cost Index (CEPCI; top), were relatively flat from March to April (the most recent data). Meanwhile, all of the Current Business Indicators from IHS Global Insight (middle), declined slightly from April to May.

According to the American Chemistry Council (ACC; Washington, D.C.; www.americanchemistry.com), in its most recent weekly report at *CE* press time, the Organization for Economic Cooperation and Development's (OECD) composite leading indicator (CLI) data for April point to a divergence between economies. The CLIs for Japan, the U.S. and Russia continue to signal improvements in economic activity. In France and Italy, the CLIs continue to point to sluggish economic activity. The CLIs for the U.K., Canada and the Euro Area as a whole continue to point toward economic activity slightly below longterm trend. The assessment for China and India has changed significantly since last month, ACC says. For both countries, the CLIs point toward economic activity below longterm trend. In Brazil the CLI continues to point toward a turning point with economic activity returning toward longterm trend but with a weaker intensity.

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

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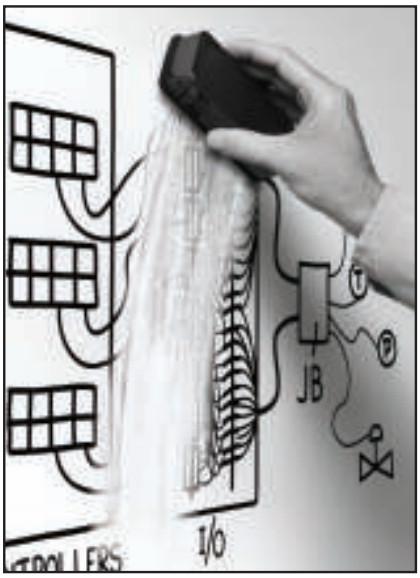

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