CHEMICAL ENGINEERING

February 2013

www.che.com

NEW DEPARTMENT

Technology Profile

Propylene Production via Propane Dehydrogenation

PAGE 33

Sizing Pressure-Relief Valves

PAGE 35

Centrifugal Pumps

Process and Product Development

Environmental Permitting for Dryers and Kilns

Facts at Your Fingertips: Steam-System Water Preparation

Recovering Phosphorus

Energy-Efficient Motors

Access Intelligence

CHEMICAL ENGINEERING

www.che.com

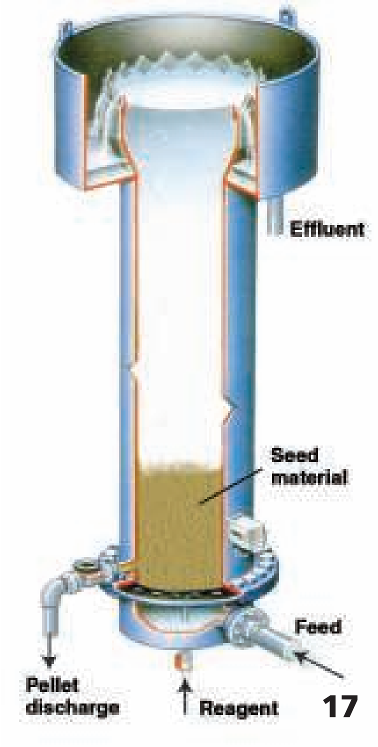
FEBRUARY 2013 VOLUME 120, NO. 2

COVER STORY

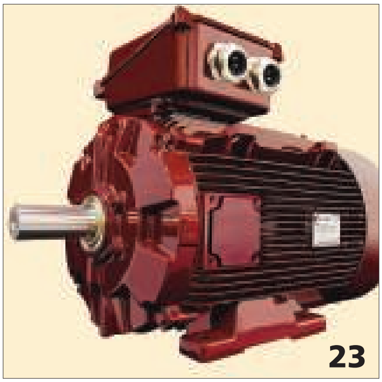
NEWS

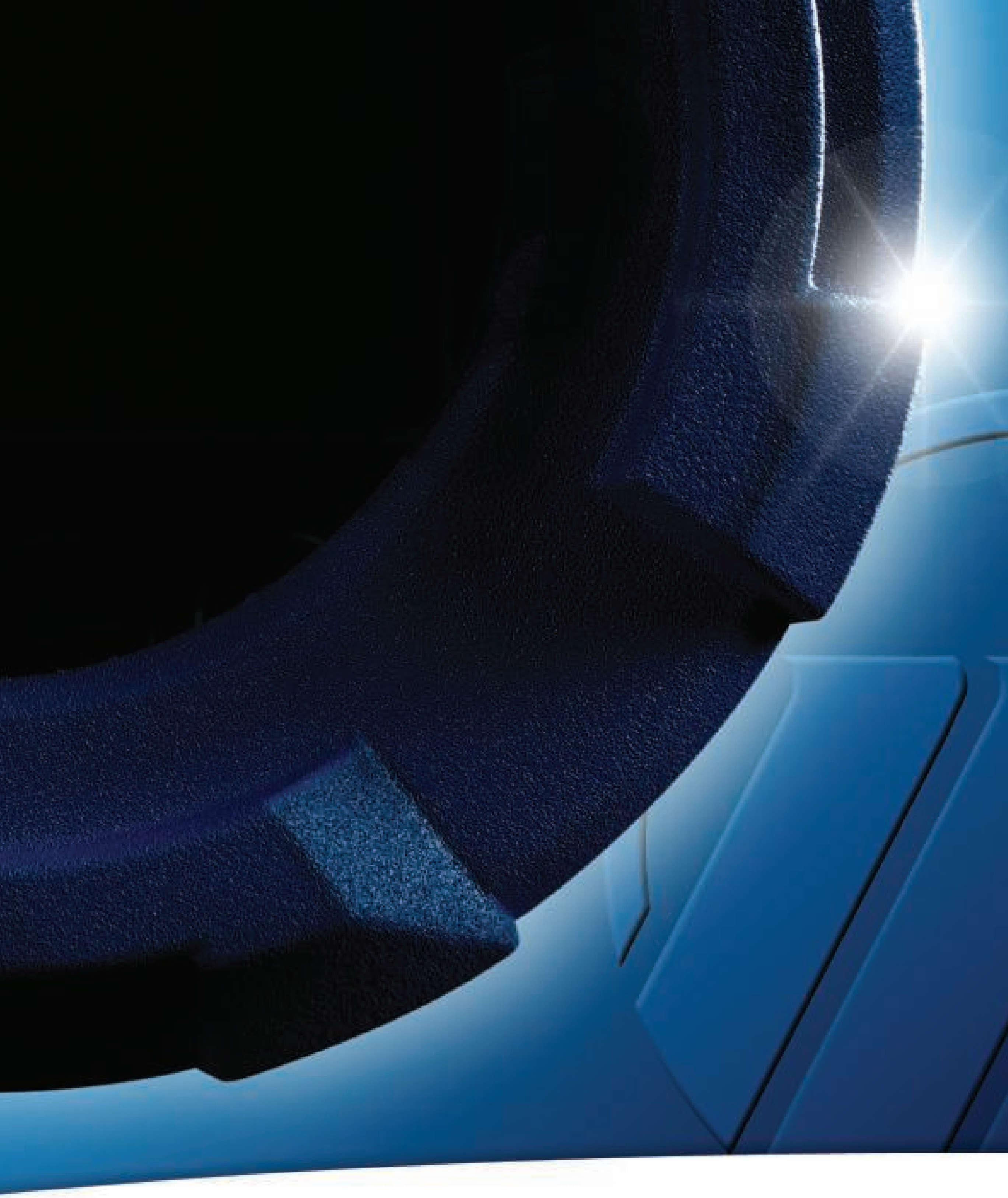
ENGINEERING


35



17


23



EQUIPMENT & SERVICES

COMMENTARY

DEPARTMENTS

ADVERTISERS

COMING IN MARCH

Look for: **Feature Reports** on Corrosion; and Heat Transfer Fluids; an **Engineering Practice** article on Turbines; an **Environmental Manager** article on Responding to a Regulatory Agency Inspection; a **Focus** on Pumps; and a second **Focus** on Bins, Silos and Storage; **News articles** on Polymer Processing; and Professional Engineer Requirements; and more

***ONLY ON CHE.COM**

Look for Latest News; additional New Products; and more

Cover: David Whitcher

Circle 20 on p. 60 or go to adlinks.che.com/45769-20

Winner of Eight Jesse H. Neal Awards for Editorial Excellence

CHEMICAL ENGINEERING

Published since 1902
An Access Intelligence Publication

PUBLISHER

BRIAN NESSEN
Group Publisher
bnessen@accessintel.com

EDITORS

DOROTHY LOZOWSKI
Managing Editor
dlozowski@che.com

GERALD ONDREY (Frankfurt)
Senior Editor
gondrey@che.com

SCOTT JENKINS
Associate Editor
sjenkins@che.com

CONTRIBUTING EDITORS

SUZANNE A. SHELLEY
sshelley@che.com

CHARLES BUTCHER (U.K.)
cbutcher@che.com

PAUL S. GRAD (Australia)
pgrad@che.com

TETSUO SATOH (Japan)
tsatoh@che.com

JOY LEPREE (New Jersey)
jlepree@che.com

GERALD PARKINSON
(California) gparkinson@che.com

INFORMATION SERVICES

CHARLES SANDS
Senior Developer
Web/business Applications Architect
csands@accessintel.com

MARKETING

JAMIE REESBY
Marketing Director
TradeFair Group, Inc.
jreesby@che.com

JENNIFER BRADY
Marketing Coordinator
TradeFair Group, Inc.
jbrady@che.com

ART & DESIGN

DAVID WHITCHER
Art Director/
Editorial Production Manager
dwhitcher@che.com

PRODUCTION

STEVE OLSON
Director of Production &
Manufacturing
solson@accessintel.com

JOHN BLAYLOCK-COOKE
Ad Production Manager
jcooke@accessintel.com

AUDIENCE DEVELOPMENT

SARAH GARWOOD
Audience Marketing Director
sgarwood@accessintel.com

GEORGE SEVERINE
Fulfillment Manager
gseverine@accessintel.com

JEN FELLING
List Sales, Statlistics (203) 778-8700
j.felling@statlistics.com

EDITORIAL ADVISORY BOARD

JOHN CARSON
Jenike & Johanson, Inc.

DAVID DICKEY
MixTech, Inc.

MUKESH DOBLE
IIT Madras, India

HENRY KISTER
Fluor Corp.

TREVOR KLETZ
Loughborough University, U.K.

GERHARD KREYSA (retired)
DECHEMA e.V.

RAM RAMACHANDRAN
(Retired) The Linde Group

HEADQUARTERS

88 Pine Street, 5th Floor, New York, NY 10005, U.S.
Tel: 212-621-4900 Fax: 212-621-4694

EUROPEAN EDITORIAL OFFICES

Zeilweg 44, D-60439 Frankfurt am Main, Germany
Tel: 49-69-9573-8296 Fax: 49-69-5700-2484

CIRCULATION REQUESTS:

Tel: 847-564-9290 Fax: 847-564-9453
Fullfillment Manager; P.O. Box 3588,
Northbrook, IL 60065-3588 email: clientservices@che.com

ADVERTISING REQUESTS: see p. 60

For photocopy or reuse requests: 800-772-3350 or info@copyright.com
For reprints: Wright's Media, 1-877-652-5295, sales@wrightsmedia.com

ACCESS INTELLIGENCE, LLC

DON PAZOUR
Chief Executive Officer

ED PINEDO
Executive Vice President
& Chief Financial Officer

MACY L. FECTO
Exec. Vice President,
Human Resources & Administration

HEATHER FARLEY
Divisional President,
Access Intelligence

DANIEL MCKINNON
Vice President,
Energy and Engineering Events

ROBERT PACIOREK
Senior Vice President,
Chief Information Officer

SYLVIA SIERRA
Senior Vice President,
Corporate Audience Development

MICHAEL KRAUS
Vice President,
Production and Manufacturing

STEVE BARBER
Vice President,
Financial Planning and Internal Audit

GERALD STASKO
Vice President/Corporate Controller

Access Intelligence
4 Choke Cherry Road, Second Floor
Rockville, MD 20850 • www.accessintel.com

BPA

Editor's Page

A partnership for process understanding

At *Chemical Engineering* magazine, we focus the bulk of our coverage on the unit operations and equipment that tie the various segments of the chemical process industries (CPI) together. Regardless of industry sector, plant engineers perform chemical, mechanical and thermal transformations of raw materials, including petroleum, minerals, air and others, into products, using a host of common processes. But while there are many parallels among the segments of the CPI, there is also incredible breadth and diversity in the process technology used in the various industries, from petrochemicals to pulp and paper, or from glass to non-ferrous metals.

To help CPI professionals better understand some of the specific processes from different industry areas, the magazine is introducing a new department, called Technology Profile. The first installment can be found on p. 33 of this issue. The one-page capsule is designed to provide a brief synopsis of a specific technology, including major process steps, key equipment and important safety or environmental considerations. In addition, the technology profile will include an economic perspective, discussing what factors make the process economically viable.

The topic of the first Technology Profile column is propylene production via propane dehydrogenation. The market for propylene has become tighter recently because of a shift to lighter feedstocks (less naptha, more ethane) for making olefins, particularly ethylene. The demand for propylene has spurred development of on-purpose propylene production technologies that can take advantage of inexpensive propane from shale deposits. Propane dehydrogenation is among the more promising technologies for fulfilling propylene demand.

To populate the Technology Profile page with the best available information, *CE* has partnered with the team of engineers at the consulting firm Intratec Solutions LLC, (Houston; www.intratec.us). Headquartered in Houston, with offices in Rio de Janeiro and New York, as well as Monterrey, Mexico and Winnipeg, Canada, Intratec is an established consulting business with expertise in conducting technological and economic assessments of mature and emerging technologies in the CPI. For the Technology Profile column, Intratec engineers, led by company director Felipe Tavares, will supply the information on the specific technologies, which will be edited for publication by *CE* editors.

Intratec is widely recognized for its independent research on the global chemical industry. For 10 years, the company has provided structured feasibility studies and process analyses on various technologies and process improvement opportunities for its clients. Intratec has pioneered a unique business model that works by charging clients a lower-than-market fee to conduct a study with the understanding that the same study may be sold, after an agreed period of time, in an unrestricted manner as a publication.

The members of the *CE* team are excited about the partnership with Intratec, and about offering the new department to its readers. I invite you to take a look at the Technology Profile column as you peruse the issue, and hope you find it to be informative and enjoyable. Please feel free to offer feedback on how to improve the department and more generally, how the magazine can better meet your needs.

Thanks for reading! ■

Scott Jenkins

Letters

Honoring pump users

ITT Goulds Pumps is now accepting nominations for the Heart of Industry Award and the Pulse of Industry Honor Roll. These recognition programs were developed as part of Pump Appreciation Day — a worldwide celebration of pumps as the heart of industry that will take place Tuesday, April 9.

"Pumps function as the heart of industry, and it's a pleasure for ITT Goulds Pumps to honor the talented people and organizations that keep pumps running smoothly and efficiently," says Robert J. Pagano Jr., president of the ITT Industrial Process business, which includes ITT Goulds Pumps. "We hope to recognize as many of these hard-working organizations and individuals as we can, and look forward to celebrating honorees as part of the second annual Pump Appreciation Day."

The Heart of Industry Award recognizes industrial operations for excellence in using pump technology to improve plant processing, satisfy customers and enhance our modern way of life. Honors will go to companies or plants nominated by ITT Goulds Pumps sales offices and distributors, with a limit of one award-winner per office. Organizations using ITT Goulds Pumps products and services are encouraged to contact their distributors to learn more.

Anyone in a pump-related industry has the opportunity to submit nominations for the Pulse of Industry Honor Roll. This individual recognition program is intended for people who want to commend co-workers and colleagues for their exceptional work in pump operations, maintenance or optimization.

A brief online nomination form is available at www.pumpappreciationday.com. Nominators have the option to include a photo and a short story about the nominee. Criteria for being honored include:

- Improving pump efficiency
- Providing outstanding maintenance
- Solving engineering or manufacturing challenges
- Exceeding expectations and providing extra effort to keep pumps running
- Exemplifying high-quality customer service

Nominations must be submitted by Friday, March 1. Following an internal review process, officials at ITT Goulds Pumps will add honorees' names to the Honor Roll on www.pumpappreciationday.com. Chosen nominees for the Heart of Industry Award and the Pulse of Industry Honor Roll will be notified by email and will also receive special recognition on Pump Appreciation Day.

Margaret Gan
Director of Communications for ITT Industrial Process

Do you have — • Ideas to air? • Feedback about our articles?
• Comments about today's engineering practice or education?
• Job-related problems or gripes to share?
If so — Send them, for our Letters column, to
Dorothy Lozowski
Chemical Engineering, Access Intelligence,
88 Pine St., 5th floor
New York, NY 10005; **letters@che.com**

NORTH AMERICA

DCAT Week 2013. Drug, Chemical and Associated Technologies Assn. (Robbinsville, N.J.). Phone: 609-448-1000; Web: dcat.org
New York, N.Y. **March 11–14**

Corrosion 2013. National Assn. of Corrosion Engineers (Houston). Phone: 800-797-6223; Web: events.nace.org
Orlando, Fla. **March 17–21**

AFPM Annual Meeting. American Fuel and Petrochemical Manufacturers (AFPM; Washington, D.C.). Phone: 202-457-0480; Web: afpm.org
San Antonio, Tex. **March 17–19**

American Chemical Soc. (ACS) National Meeting and Exposition. ACS (Washington, D.C.). Phone: 202-872-4600 Web: acs.org
New Orleans, La. **April 7–11**

Interphex 2013. Reed Exhibitions (Norwalk, Conn.). Phone: 203-840-5648; Web: interphex.com
New York, N.Y. **April 23–25**

AIChE 2013 Spring Meeting and 9th Global Congress on Process Safety. AIChE (New York, N.Y.). Phone: 800-242-4363; Web: aiche.org
San Antonio, Tex. **April 28–May 2**

International Refinery Energy Power (IREP) Conference. Hydrocarbon Publishing Co. (Philadelphia, Pa.). Phone: 610-408-0116; Web: irepconference.com
Houston **May 1–3**

AspenTech Optimize 2013 Global Conference. Aspen Technology (Burlington, Mass.). Phone: 855-882-7736; Web: aspentech.com/agc/
Boston, Mass. **May 6–8**

7th Annual ACEEE Energy Efficiency Finance Forum. American Council for an Energy-Efficient Economy (ACEEE; Washington, D.C.). Phone: 202-507-4000; Web: aceee.org/conferences/2013/eeff
Portland, Ore. **May 13–15**

15th Annual Electric Power Conference and Exhibition. Tradefair Group, an Access Intelligence LLC Co. (Houston). Phone: 832-242-1969; Web: electricpowerexpo.com
Chicago, Ill. **May 14–16**

Circle 1 on p. 60 or go to adlinks.che.com/45769-01

Calendar

AFPM Reliability & Maintenance Conference and Exhibition 2013. American Fuel and Petrochemical Manufacturers (AFPM; Washington, D.C.). Phone: 202-457-0480; Web: afpm.org
Chicago, Ill. **May 14–16**

AWMA Annual Conference. Air & Waste Management Assn. (Pittsburgh, Pa.). Phone: 412-232-3450; Web: awma.org
Chicago, Ill. **June 25–28**

EUROPE

Global ManuChem Strategies 2013. We-Conect Global Leaders GmbH (Berlin, Germany). Phone: +49-30-5210-703; Web: we-conect.com
Berlin, Germany **February 25–26**

PVC Formulation 2013. Applied Market Information LLC (Wyomissing, Pa.). Phone: 610-478-0800; Web: amiplastics-na.com
Düsseldorf, Germany **March 12–14**

Powtech. Nuremberg Messe (Nuremberg, Germany). Phone: +49-911-8606-8355; Web: powtech.de/en/
Nuremberg, Germany **April 23–25**

11th Workshop on Polymer Reaction Engineering. Dechema e.V. (Frankfurt am Main, Germany). Phone: + 49-69-7564-0; Web: dechema.de/pre2013
Hamburg, Germany **May 21–24**

21st European Biomass Conference and Exhibition. ETA Florence Renewable Energies (Florence, Italy). Phone: +39-55-500-2280, ext. 221; Web: conference-biomass.com
Copenhagen, Denmark **June 3–7**

ASIA & ELSEWHERE

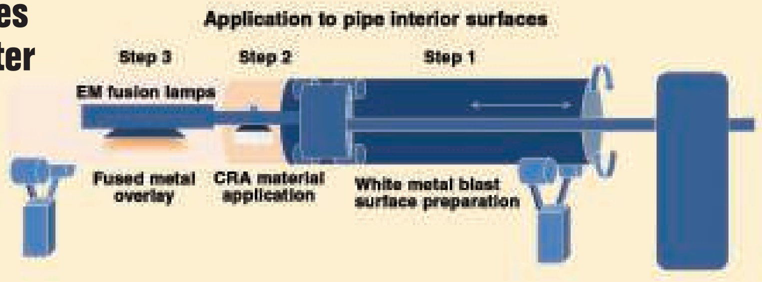
MasterBatch Asia 2013. Applied Market Information LLC (Wyomissing, Pa.). Phone: 610-478-0800; Web: amiplastics-na.com
Singapore **March 18–20**

World Coal-to-Liquids (CTL) 2013. World CTL (Paris). Phone: +33-607-28-5247; Web: world-ctl.com
Shanghai, China **April 16–19**

AchemAsia 2013. Dechema e.V. (Frankfurt am Main, Germany). Phone: +49-69-7564-277; Web: achemasia.de
Beijing, China **May 13–16** ■

Suzanne Shelley

This pipe-cladding process applies corrosion-resistant coatings faster



The surface engineering company MesoCoat, Inc. (Euclid, Ohio; www.mesocoat.com) recently started up a facility for manufacturing clad pipe for the oil-and-gas industry that uses the company's proprietary fusion-cladding technology to apply corrosion-resistant alloys to carbon-steel pipes. Because the cladding can be applied to large areas at very high speeds, the technology can be used to coat much larger equipment and components, and at lower prices than laser-cladding processes or weld-overlay-type coating processes.

MesoCoat's cladding technology, known as CermaClad (diagram), can lead to a reduction of 50% or higher in life-cycle costs, explains MesoCoat CEO Andrew Sherman, because it extends the lifetime and also lowers the initial capital costs of large chemical assets. CermaClad applies a corrosion-resistant coating up to 40 times faster than laser cladding processes, and provides significantly better metallurgical properties compared to weld overlay alternatives.

The technology, first pioneered at Oak Ridge National Laboratory (Oak Ridge, Tenn.; www.ornl.gov), essentially enables melting and fusing of any metal or ceramic on metal substrates. CermaClad applies the cladding or coating material as a powder or paint to the surface, and then uses a high-intensity, plasma-arc lamp to produce radiation that is focused on tubular or flat metal surfaces with mirror reflectors. The radiation rapidly fuses the corrosion- and wear-resistant alloy to the surface of 12-m pipes or other large equipment. "We call the plasma-arc lamp an 'artificial sun,' since it generates a heat spectrum close to that of the sun," says Sherman. The coating is applied at thicknesses of 0.1 to 4 mm depending upon the environment to which the metal will be exposed.

Using the CermaClad process, MesoCoat's new facility will first produce pipes with a corrosion-resistant alloy cladding needed for handling high-sulfur sour oil and gas. The company anticipates that the CermaClad technology will eventually be used in the petroleum-refining, fluegas-desulfurization, pulp-and-paper, and chemical-transport industries for piping and vessels, as well as for other large equipment, such as heat-exchanger tube sheets.

A process for recovering rare-earth metals from magnet scrap

Researchers at the U.S. Dept. of Energy's (DOE) Ames Laboratory (Ames, Iowa; www.ameslab.gov) led by Ryan Ott have developed a process for recovering rare-earth (RE) metals from magnet scraps. The process involves first crushing neodymium-iron-boron magnet scraps and placing the pieces in a stainless steel crucible, to which chunks of magnesium metal are added. The apparatus is heated in a specially modified radio-frequency furnace, which melts the magnesium and promotes stirring, thereby speeding diffusion. Ames Laboratory's Ott explains that since RE metals have good solubility in molten magnesium, they diffuse out of the magnet material and into the molten magnesium, while iron and boron, which have negligible solubility in magnesium, remain behind. Following the casting of the Mg-RE alloy, the magnesium is removed by vacuum distillation so that it can be used for another round of melting, and the rare-earth metal is isolated.

The team reports that permanent magnets made with recycled RE metals have intrinsic properties similar to permanent magnets synthesized from RE metal ore. Ott's current project builds on knowledge gained in a 1990s-era Ames Laboratory project for using RE metals in magnesium alloys.

Ott says his team of researchers has demonstrated the process on 2 kg of scrap at a time, and is working on optimizing the extraction by experimenting with Mg-to-scrap ratios, processing time and temperatures. The team is also working on scaling up the process by an order of magnitude.

Nitrogen fixation

The research groups of Yoshiaki Nishibayashi at the University of Tokyo (Japan; park.itc.u-tokyo.ac.jp/nishiba) and Kazunari Yoshizawa at Kyushu University (Fukuoka, Japan; trout.scc.kyushu-u.ac.jp/yoshizawaJ/indexe.html) have demonstrated the production of silylamine [$N(SiMe_3)_3$] from nitrogen gas using an iron-based catalyst. The reaction takes place at room temperature and pressure using sodium as a reducing agent and chloro-trimethylsilane as a silylation agent over an inexpensive Fe-based catalyst, such as iron pentacarbonyl [$Fe(CO)_5$] or ferrocenes.

Because $N(SiMe_3)_3$ is quantitatively converted into ammonia by simply adding water, this new route to $N(SiMe_3)_3$ could someday be an alternative to the energy-intensive Haber-Bosch process.

Iron-based HTS

Copper-oxide high-temperature superconductors (HTS) are a leading candidate for advanced energy applications, but these ceramic materials are brittle and require costly, complicated multilayer synthesis procedures, according to Brookhaven National Laboratory (BNL; Upton, N.Y.; www.bnl.gov). A promising alternative has been discovered by a collaboration led by BNL: an iron-chalcogenide-based superconducting film. Iron-based superconductors are mechani-

(*Continues on p. 12*)

Note: For more information, circle the 3-digit number on p. 60, or use the website designation.

Oxidation-based water-reuse technology that improves mass transfer

A water-recycling system for the oil-and-gas industries developed by Ecosphere Technologies Inc. (Stuart, Fla.; www.EcosphereTech.com) is designed to destroy bacteria and control corrosion in high-volume wastewater-treatment applications using a proprietary oxidation process.

The technology, called Ozonix, improves the mass-transfer efficiency of ozone with a Venturi system in which negative pressure created by high-velocity feed water passing through the Venturi tube draws ozone into the water more efficiently than bubble diffusion. Once the O_3 is drawn into the water, the Ozonix system uses hydrodynamic and acoustic cavitation to create tiny collapsing bubbles that convert the O_3 to hydroxyl radicals. Inside the Ozonix reactor, the hydroxyl radicals destroy bacterial cell walls, and oxidize contaminants, returning water that is ready for reuse in future operations. The imploding bubble phenomena cause localized heating of the water to over 900°F. The Ozonix system also has a specially designed electrochemical cell that precipitates metal salts and removes scale-forming compounds.

Covered by multiple patents, the Ozonix system is integrated into a custom-designed, 53-ft trailer that can be transported onto an oil-and-gas hydraulic fracturing site or to the site of another industrial water application, such as mining, agriculture, municipal wastewater and renewable energy.

By eliminating the need for liquid chemicals, the Ozonix technology reduces operating costs, since no secondary waste is created, explains George Chapas, director of business development at Ecosphere. The Ozonix system processes water in realtime (no significant residence time) at flowrates up to 5,000 gal/min. It has been used in all major shale plays in the U.S. on over 2 billion gallons of water, with chemistries typical of hydraulic-fracturing flowback water and produced water from more than 600 oil and natural gas wells.

Spun carbon-nanotube fibers with unmatched properties of any other material

For the first time, it has become possible to spin carbon nanotubes (CNTs) into a fiber that looks and acts like textile threads, yet has the electrical conductivity and strength of a metal. The breakthrough, which came after more than ten years of research, was published in the January 11 issue of *Science* by scientists from Rice University (Houston; www.rice.edu), Teijin Aramid B.V. (Arnhem, The Netherlands; www.teijnaramid.com), the Air Force Research Laboratory (Dayton, Ohio, www.afrl.af.mil) and Technion-Israel Institute of Technology (Haifa; www1.technion.ac.il).

The spinning process to make the CNT fibers is similar to that used by Teijin for making its Twaron aramid fibers. One key to the achievement was finding the right solvent for making concentrated solutions of dissolved CNTs. To make the CNT fibers, a concentrated solution of CNTs in the superacid chlorosulfonic acid is extruded through 19 tiny holes into a bath, where the CNTs precipitate. Another key was ensuring that the CNTs are perfectly aligned and packed as they form the thread. Spools of the fibers with 50-m length have been produced and can be seen in a video on Rice University's website. Because the process is based on industrially proven technology, it is readily scalable.

The new fibers have about ten times the tensile strength and electrical and thermal conductivity of the best previously reported wet-spun CNT fibers, according to Matteo Pasquali, Rice professor of chemical and biomolecular engineering and chemistry. The fibers' electrical conductivity is "on par with copper, gold and aluminum." "We finally have a nanotube fiber with properties that don't exist in any other material," he says.

The research was funded by Teijin Aramid and its parent company, Teijin Ltd. Teijin Aramid is currently trialing samples of CNT fiber on a small scale with prospective customers. The fiber is expected to have many applications in aerospace, automotive, medical and "smart" clothing industries.

(*Continued from p. 11*)

cally semi-metallic, and thus considerably less fragile than the copper-based ceramic films, and can be more readily shaped into long wires needed for devices, says BNL.

The films — composed of iron, selenium and tellurium — are made by pulsed-laser deposition, which uses a high-power laser to vaporize materials that are collected in layers on a substrate. Adding layers of cesium oxide in between the films and substrates was found to greatly enhance the HTS' critical current density, as well as increase the critical temperature at which the material becomes superconducting.

Nuclear-waste sponge?

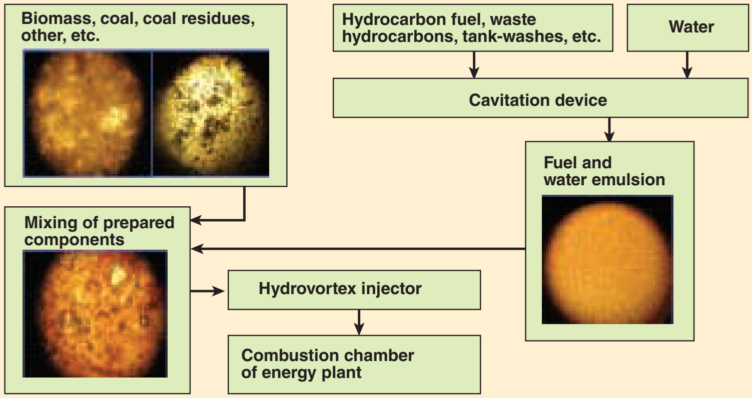
Chemists from Rice University and Lomonosov Moscow State University (Russia; www.msu.ru) have shown that thin flakes of graphene oxide quickly adsorb radionuclides from wastewater and coagulates into solids. The high surface area of the graphene oxide combined with graphene's unique properties not only gives the material a high adsorption capacity for toxins, but also very fast reaction kinetics. With these superior properties, graphene oxide could be a better alternative than the bentonite clays and granulated activated carbon commonly used in nuclear cleanup. The researchers say the material could cut the cost of hydraulic fracturing for oil-and-gas recovery, as well as for treating wastewater from rare-earths and other mines.

Methane-to-diesel

Motivating microbes to metabolize more methane into lipids, which can be processed into liquid diesel fuels, is the goal of a new research project led by the DOE's National Renewable Research Energy Laboratory (NREL; Golden, Colo.; www.nrel.gov). Participants in the $4.8-million ARPA-E project (see also story on p. 15) include the University of Washington (Seattle; www.washington.edu), Johnson Matthey (London, U.K.; www.matthey.com) and LanzaTech (Roselle, Ill.; www.

(*Continues on p. 14*)

New boiler fuels from oil, coal and biomass wastes



Composite liquid and slurry boiler fuels have been produced from mixtures of various waste materials, such as biomass, coal- and crude-oil-processing residues, wood and other combustible substances, in a collaboration between researchers at the University of Rhode Island (Kingston, R.I.) and Podgorny Institute (Kharkov, Ukraine). The researchers have formed a company, InEnergy LLC (Naples, Fla.; www.inenergycorp.com) and are seeking partners to scale up the process. The technology promises to be a low-cost source of composite fuels, as well as a way to clean up the environment, says Harold Knickle, vice president of InEnergy and a professor of chemical engineering at the University of Rhode Island.

The process (flowsheet), which is continuous, is called PHCR, for "Pump, Homogenizer, Cavitation and Reactor." Liquid and solid wastes are fed separately into the system, prepared, then combined to produce a composite fuel. A key element of liquid processing is hydrodynamic cavitation, in which liquid hydrocarbon wastes are mixed with 5–25% water to form a fuel-and-water emulsion. The cavitator, which has multiple high-speed rotors, breaks the bonds of 5–7% of the water, releasing hydrogen that reacts with the hydrocarbons to upgrade their fuel value. Depending on the type of fuel, the emulsion may then be mixed with finely ground (100–200 µm) solid wastes to obtain the desired boiler fuel.

So far the process has been piloted at a scale of 400 gal/h. The products have included diesel fuel from a mixture of 70% waste heavy oil, 15% diesel fuel and 15% water; and heating oil, similar to No. 2 heating oil, from bitumen tar and water. Also, composite slurry fuels have been injected into actual boilers, where it was learned that they cannot be put through standard injectors because they block the fuel lines and orifices. Knickle says that problem has been solved by developing new injectors.

This molecular sieve has a 'trapdoor' to selectively pass CO_2

An Australian team has developed a new molecular sieve that allows carbon dioxide molecules to be trapped and stored. Contrary to the way molecular sieves usually work, allowing smaller molecules through, the new sieve acts like a trapdoor, and allows larger molecules through, blocking smaller ones. The team, led by professor Paul A. Webley of the University of Melbourne (Australia; www.unimelb.edu.au), believes an important application of the sieve is in natural gas purification.

The team also includes members of the Cooperative Research Center for Greenhouse Gas Technologies (www.co2crc.com.au), the Australian Synchrotron (www.synchrotron.org.au), Monash University (www.monash.edu.au), ARC Center of Excellence for Electromaterials Science (www.arc.gov.au), CSIRO Materials Science and Engineering and CSIRO Process Science and Engineering (all in Melbourne, Victoria, Australia; www.csiro.au).

Through a combination of experimental and computational approaches, the team claims it has shown that "for a class of chabazite zeolites, what appears to be molecular sieving based on dimension is actually separation based on a difference in ability of a guest molecule to induce temporary and reversible cation deviation from the center of pore apertures, allowing for exclusive admission of certain molecules," says Webley. This permits a counter-intuitive size-inverse separation.

The team has synthesized chabazite materials with various silicon-to-aluminum ratios and cation types and performed adsorption experiments with CO_2, N_2 and CH_4. It observed that the accessibility of adsorption sites to gas molecules in certain types of chabazites is temperature-dependent. Thus, a specific gas can only be adsorbed above a certain temperature — the "critical admission temperature", or pore-blockage temperature — for that specific gas. Certain chabazites exhibit high selectivities of CO_2 over N_2 and CH_4 at certain temperatures over a large pressure range.

lanzatech.com). The University of Washington will focus on genetically modifying microbes; NREL will develop the fermentation process to demonstrate the productivity as well as the process to extract the lipids; Johnson.Matthey will produce the catalyst for converting the lipids into diesel fuel; and Lanza Tech will move the bench-scale process (if successful) to commercial scale.

Making MOFs

Researchers at Aldrich Materials Science, a strategic technology initiative of Sigma-Aldrich Corp. (St. Louis, Mo.; www.sigma-aldrich.com), have discovered a way to make metal oxide frameworks (MOFs) under completely liquid-free conditions. The scientists demonstrated the synthesis of Y-MOF using a room-temperature ball-milling process, whereby yttrium hydride is milled with solid, high-melting trimesic acid to form Y-MOF. The only byproduct observed from the process is hydrogen gas. The solvent-free synthesis is said to yield MOFs of "exceptional purity" by preventing contamination from solvents and liquid residues. A patent for the process was filed prior to publishing the results, which first appeared (online) in *Chem. Communications*.

MOFs are hybrid structures combining multi-functional organic molecules and metal ions in a 3D network, with potential applications in gas storage, separation, catalysis, sensors and more. ❏

Electrochemistry may have a future in CO_2 cleanup

An electrochemical process that could cut the energy and cost requirements for stripping carbon dioxide from stack gases by half is being developed at Arizona State University (ASU, Tempe; www.asu.edu). At present the only commercially viable technology is CO_2 absorption by monoethanolamine (MEA), says Dan Buttry, chair of ASU's Department of Chemistry and Biochemistry. However, he notes that a recent report from the U.S. Dept. of Energy (DOE; Washington, D.C.; www.energy.gov) says the thermal energy to regenerate MEA consumes roughly 40% of total power plant output and increases the cost of electricity by 85%.

In contrast, ASU's system — which has similarities to a fuel cell — uses only a small voltage difference (about 0.5 V) to capture and release CO_2, with no temperature cycle. The system consists of two porous carbon electrodes, separated by a polymer membrane. Gases are fed through a serpentine channel across the face of the cathode, which is impregnated with an ionic liquid containing reagent precursors. These are reduced to nucleophiles at the cathode and react with CO_2 to form adducts. The adducts pass through the membrane and are oxidized at the anode to recover CO_2, while the precursor returns to the cathode.

A novel element in the process is that the adduct is a type of thiocarbonate that "is barely known in the literature," says Buttry. So far, he says, the process has been tested in the laboratory, using "clean" gas that contains CO_2. Now the university is planning to start tests using flue gas under a $612,000 grant from DOE's Advanced Research Projects Agency-Energy (ARPA-E).

Continuous production of 'Bio-cokes'

Kinki University (www.kindai.ac.jp) and Naniwa Roki Co. (both Osaka, Japan; www.naniwaroki.co.jp) have developed a continuous process for producing a next-generation solid fuel, called Bio-cokes. The process is being used at a new production facility located at Kinki University Research Institute of Bio-cokes (Eniwa City, Hokkaido), established last December. The new facility has four times the capacity and requires one fifth the energy as the existing batch-type production facility, which started up in 2011.

The previous production method required many steps, including filling and compressing of raw materials into the cylindrical reactor, heating and cooling of the compressed materials within the cylinder, removing and then cutting the Bio-cokes products into pieces. Now, the researchers have adopted a piston-flow process that performs all the steps continuously. The continuous process has improved heating capabilities for reducing the energy consumption. The facility, with 36 cylindrical reactors, can produce 28 ton/d of Bio-cokes.

The process converts biomass, such as waste coffee grain and tea leaves into Bio-cokes, which can be used as replacements for coal-derived coke. Using Kinki University technology, Osaka Prefecture Forest Owners Assn. already started the world's first commercial production of Bio-cokes

(*Continues on p. 16*)

Physical chemistry principles point to a better way to clean up oil spills

One of the current methods for dealing with oil spills is through the use of dispersants. These dispersants, however, break oil into small globules that sink into the water, spreading the oil into a wider area, and they have toxic effects on the local marine ecosystem. Now, researchers, led by professor Moses O. Tade at the Dept. of Chemical Engineering at Curtin University (Perth, Western Australia; www.curtin.edu.au), have developed a cleaner method for treating oil spills — the "floating droplet solution".

The researchers studied (theoretically and experimentally) the floatability of water on an oil surface. Their numerical model was developed from the Young-Laplace equation on three interfaces (water/oil, water/air and oil/air) to calculate the theoretical equilibrium. According to the researchers, the model compared well with experimental data of a water/vegetable-oil system.

They showed that water droplets can float on an oil surface due to a combination of interfacial tensions and buoyancy, up to a certain volume. The equilibrium contact angle should be greater than 5 deg. in order for a water droplet to float.

A potential application of the phenomenon involves using small water droplets on oil spills floating in the ocean to facilitate aerobic biodegradation. The efficiency of oil biodegradation depends on the level of dissolved oxygen, water-oil interfacial area, and bacterial/nutrient availability. Since most oils are lighter than water, these tend to cover the water surface and prevent atmospheric oxygen from dissolving into the water. Small water droplets can have a large water-oil contact area as well as concentrated, selected bacterial populations. Also, these surface droplets can maintain a high level of dissolved oxygen due to direct exposure to air. The three interface tensions can be easily manipulated with the wide range of available surfactants to stabilize the water droplets in any oil.

The proof-of-concept has been demonstrated in the laboratory using fuel oil. Now, the researchers are working on a simulation of ocean conditions and testing with crude oil samples. The university is seeking partners and licensees to complete testing and develop a product. ■

BIO-COKES (*Continued from p. 15*)

in April 2011 (*Chem. Eng.*, June 2011, p. 14) using forest thinning as raw materials, and the products are being used as a partial supplement for coal-derived cokes in a cupola furnace for the production of automobile engine parts by Toyota Industries Corp. Kinki University technology is also used as an alternative to coal-based coke in a high-temperature gasification furnace for treating waste.

P-RECOVERY ON THE MOVE

Instead of removing phosphates from waste streams, technology is now emerging to recover this vital resource

Unlike fossil fuels or precious metals, phosphorus has no alternatives — we (and all other life forms on the planet) need phosphorus; it's in our DNA, our bones and our energy-producing chemicals (ATP). We get it from our food — meat, grains and vegetables — so it's not surprising that phosphorus is a key ingredient in fertilizer, as well as a component of sewage, manure and slaughterhouse waste (bone meal).

Sewage, for example, contains about 1–2% phosphorus. Although some of this phosphorus can be "recycled" by land application of sewage sludge on farmland, plant uptake is limited because the phosphorus is bound as compounds that can't be metabolized. As a result, the unused phosphates find their way into waterways (runoff), causing eutrophication of rivers and lakes.

In addition, the practice of spreading manure and sewage sludge is coming under scrutiny for health and safety reasons due to the presence of other pollutants, such as organic compounds and heavy metals. In Germany, for example, about half of the sewage sludge generated is still used for land application, but the practice is now forbidden in two states (Bavaria and Baden-Württemberg); and environmental legislation tends to be one directional — more stringent, never less.

More critical than environmental concerns, perhaps, is the realization that phosphorus supplies are not only limited (some experts predict "peak phosphorus" occurring in 2030, and a depletion of phosphorus-rock mines occurring in the next 50–100 years), but are also in the hands of a few. Phosphate rock reserves (as P_2O_5) are estimated to be 71 billion tons, with 70% coming from Morocco and the Western Sahara region, according to U.S. Geological Survey (USGS; Reston, Va.; www.usgs.gov). Global mining production in 2011 was 191 million tons, according to the USGS.

The E.U. is particularly hard pressed, with only one phosphate mine (in Finland). As a result, efforts have been underway in recent years to develop technologies to recycle phosphorus, especially from sewage and other waste streams. Last May, these efforts also received a political impetus when the European Parliament adopted "A Resource-efficient Europe," a resolution that includes, among other things, a call to the Commission and Member States for "achieving virtually 100% reuse [of phosphorus] by 2020, and optimizing [its] use and recycling." E.U. funding for research into pilot projects was also emphasized.

Industry leads

Meanwhile, companies in the chemical process industries (CPI) have already developed technologies for removing phosphates from wastewater, not only for environmental reasons, but also to prevent fouling during the operation of wastewater treatment plants (WWTPs). These technologies are now being adapted — and new technologies are emerging — to recover, rather than simply remove, the phosphates in a form that can make money, namely as fertilizers.

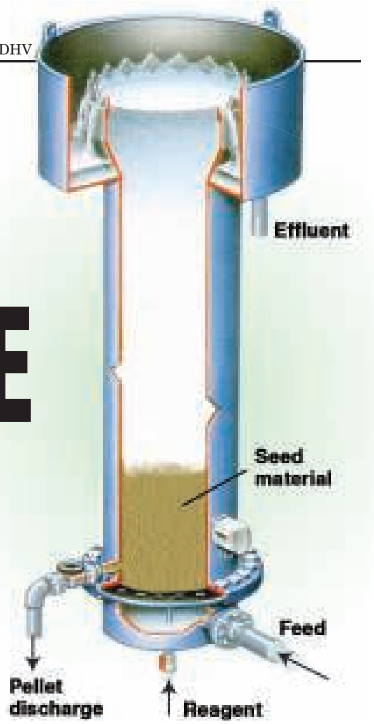


FIGURE 1. The Crystalactor technology recovers phosphorus as struvite crystals that form on seed particles

Already two years ago in a presentation at the International Conference on Nutrient Recovery and Management (Miami, Fla.; January 9–12, 2011), Christian Sartorious, project leader at the Fraunhofer Institute for Systems and Innovation Research (Karlsruhe, Germany; www.isi.fraunhofer.de) identified 22 phosphorus recovery (P-recovery) technologies at all stages of commercial development — from laboratory and pilot to full-scale implementation. These P-recovery methods can be broadly grouped into two categories: wet methods, in which the phosphorus is recovered at the WWTP; or thermo-chemical routes, which recover phosphorus from the ash left behind after sludge incineration. Some of these technologies are presented below.

Wet methods

Conventional phosphorus-treatment technology relies on chemicals (typically ferric chloride or alum) to convert dissolved phosphorus into an insoluble precipitate that can be settled and removed from the liquid stream as a sludge, explains Steve Wirtel, senior vice president for Nutrient Recovery at Ostara Nutrient Recovery Technologies Inc. (Ostara; Vancouver, B.C., Canada; www.ostara.com). Chemical addition is a simple process that requires minimal equipment, so it has a low capital cost. But, the process has a high operating cost because substantial amounts of chemicals are required. Chemical addition also falls short because the process binds the phosphorus into a chemical sludge where it cannot be recovered for its nutrient value as a fertilizer, says Wirtel. "And it is not environmentally friendly."

Instead of creating a chemical sludge, Ostara has developed its Pearl process, which converts dissolved phosphorus into pure (99.5%) struvite ($MgNH_4PO_4 \cdot 6H_2O$) crystals. "The process has virtually no carbon footprint and sustainably recovers a precious resource," says Wirtel. The struvite crystals are created and bagged onsite and marketed as a slow-release, enhanced-efficiency fertilizer to blenders that sell to nurseries, golf courses, and specialty agricultural growers under the brand name Crystal Green.

Ostara's proprietary Pearl process is based on the initiation and precise control of a chemical-precipitation reaction in a fluidized-bed reactor. The typical feedstreams in the process are sludge liquids produced at municipal WWTPs and "high strength" industrial used-water streams, says Wirtel. Pearl's chemical process removes phosphorus and other nutrients from the feedstreams, with phosphorus removal performance typically averaging approximately 90%, he says. The capital cost of a nutrient recovery system is recovered through the avoided cost of adding chemicals needed to precipitate phosphorus. The typical payback period range is 2–7 yr, says Wirtel.

The Pearl process was first scaled up in 2006, with the commissioning of a 500,000-L/d demonstration plant at the Edmonton Gold Bar sewage-treatment works (*CE*, November 2006, p. 13). The first commercial nutrient-recovery facility was launched with Clean Water Services (Hillsboro, Ore.) in 2009 at its Durham Advanced Wastewater Treatment Plant. Since then, Ostara has built facilities in Suffolk, Va.; York, Pa.; and a second facility with Clean Water Services at its Rock Creek Wastewater Treatment Facility in Hillsboro, Ore. In 2013, Ostara will launch three additional nutrient-recovery facilities: at Thames Water in the U.K., in Saskatoon — the first commercial facility in Canada — and in Madison, Wisc.

Another "wet" process for phosphorus recovery is the Crystalactor technology offered by Royal HaskoningDHV (Amersfoort, The Netherlands; www.royalhaskoningdhv.com). The process is based on the selective crystallization of targeted compounds, such calcium from water for water softening. Other pollutants can be crystallized as well, such as heavy metals or fluorides from the semiconductor industry or specific ions in the concentrate from desalination plants. The company has also adapted the Crystalactor technology for P-recovery from wastewater.

The heart of the patented Crystalactor process is a fluidized-bed pellet reactor (Figure 1). Wastewater is fed to the bottom of the reactor and flows upwards, fluidizing the bed of seed particles, such as sand or crushed and classified crystals. By adjusting the pH and dosing of reagents, phosphates from the waste stream crystallize as struvite or calcium phosphate onto the seed particles. As the pellets grow, they travel downwards to be discharged at the bottom of the reactor. The four steps commonly required in conventional phosphorus treatment processes — coagulation, flocculation, separation and dewatering — are combined in one by the Crystalactor, says the company.

One of the applications of the Crystalactor for P-removal is running at a dairy in Waupun, Wisc., where U.S.-licensee Procorp Enterprises (Milwaukee, Wisc.; www.procorp.com) installed a Crystalactor unit in 2005. The unit, with a 3-m dia. reactor, handles 125 m^3/h of wastewater with a phosphorus concentration of 25 mg/L, and uses quartz sand as seed. By adding lime, calcium phosphate is crystallized, and the pellets are dried for recycling.

Since the early 1990s, eight Crystalactor units have been built specifically for P-recovery, says the company.

Last August, pilot testing began on an electrochemical P-recovery process being developed at the Fraunhofer Institute for Interfacial Engineering and Biotechnology (IGB; Stuttgart, Germany; www.igb.fraunhofer.de). Unlike conventional precipitation methods, which require the addition of magnesium salts (for struvite formation) along with NaOH for adjusting the pH, the patented process uses a sacrificial magnesium electrode that generates the required Mg^{+2} ions, as well as raises the pH to 9 by the water-splitting reaction that occurs at the other electrode ($2H_2O \rightarrow H_2 + 2OH^{-1}$). The Mg^{+2} ions react with phosphates in the wastewater and precipitate out of solution as struvite crystals that can be dried and used directly as fertilizer. Plant yield and plant nutrient-uptake with the struvite were found to be up to four-times higher than with commercially available mineral fertilizers, says IGB.

The 1-m^3 pilot plant is mobile, enabling tests to be performed at a variety of wastewater treatment plants. The first tests have commenced at an agricultural biogas plant that processes corn, manure and some waste from the food-processsing industry. IGB's commercial partners are Geltz Umwelt-Technologie GmbH (Niefern-Öschelbronn; www.geltz.de), E.R.S. GmbH & Co. KG (Osterburken; ers-gmbh.de) and Bamo IER (Mannhein; all Germany; www.bamo.de). All commercialization of the technology will be promoted within this consortium.

Meanwhile, an initiative to recover phosphorus from flyash was initiated in May 2011 between the phosphate-technology company, EcoPhos S.A. (Louvain-la-Neuve, Belgium; www.ecophos.com), the sludge-processing company Silbverwerking Noord-Brant N.V. (SNB; Moerdijk; www.snb.nl) and the utility company HVC (www.hvcgroep.nl). The two Dutch companies process more than half of the sewage sludge in The Netherlands at incineration plants in Dordrecht and Moerdijk, which generate flyash residue with a phosphorus content comparable to low-quality ore.

The companies have developed a hydrometallurgical method for recovering the phosphorus in the flyash, which is expected to yield up to 250 metric tons (m.t.) of phosphate from every 1,000 m.t. of flyash.

A commercial-scale plant is planned to go onstream in 2014, which will co-process phosphate rock supplemented with about 20% flyash. The product will then be used for the production of fertilizer. In the past, flyash has been used as filler in asphalt for roads and surfaces.

Thermo-chemical methods

Although wet P-recovery methods have the advantages of maturity (due to the need to remove phosphates to avoid scaling issues) and feasibility at the relatively small scales typical of municipal WWTPs, dairies and so on, they all have the disadvantage of recovering only the dissolved phosphates, says Ludwig Hermann, senior consultant, Energy at Outotec GmbH (Oberursel, Germany; www.outotec.com). Dissolved phosphorus is typically about 25% of the total phosphorus content in sewage, and sometimes much less, he says. The rest remains in the sludge, which must be treated by other methods. With the increasing use of sludge incineration, especially in Europe, the unrecovered phosphorus has typically found its final resting place in the discharged flyash, which ends up as supplements to road pavement and concrete. In developed countries, some few hundred incinerators are producing around 3 million m.t./yr of ash every year with phosphorus concentrations up to 25 wt.% (dry). Without treatment, such ash is unsuitable as fertilizer because of high heavy-metal content and limited plant availability, says Hermann. Now, methods to recover the phosphorus from the ash — so-called urban mining — are now slated for commercialization.

One such process is the Ash Dec technology, which Outotec acquired in 2011 from Ash Dec Umwelt AG (Vienna, Austria). The process recovers almost 100% of the phosphorus, as well as other metals present in the ash, while producing a marketable fertilizer.

Source: Outotec

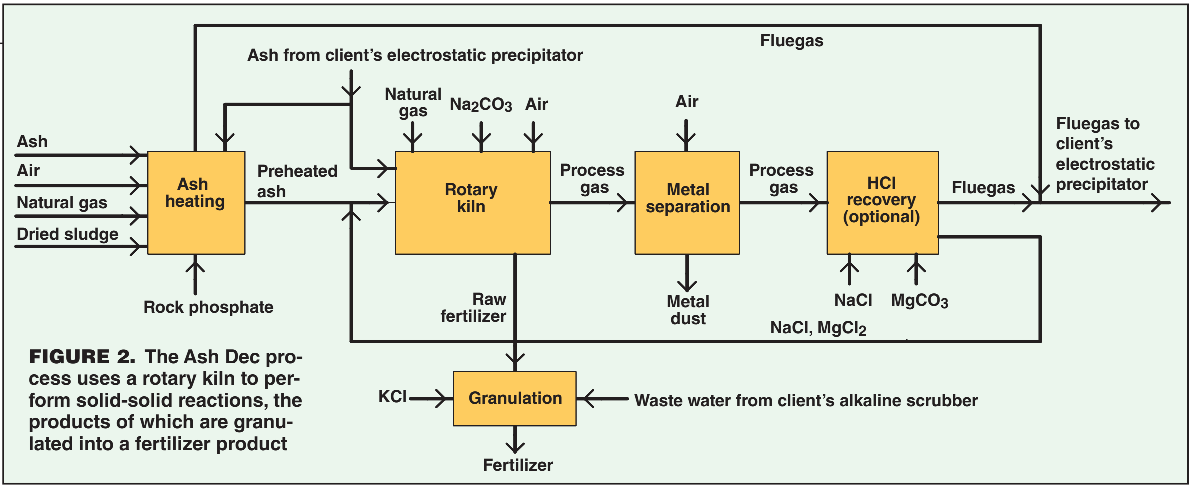


FIGURE 2. The Ash Dec process uses a rotary kiln to perform solid-solid reactions, the products of which are granulated into a fertilizer product

In Ash Dec (Figure 2), magnesium salts and ash are fed to a rotary kiln reactor operating at 1,000°C. Toxic metals are vaporized, and exit the kiln with the process gas to be captured as dust by the air-pollution control system. At the same time, the solid $MgCl_2$ reacts (residence time about 20 min) with the ash-borne phosphorus to produce calcined phosphate. This is then sent to a granulation unit, where it is combined with potassium salts to form granular fertilizer products. These fertilizers contain 99% less cadmium and 90% less uranium than most phosphate-rock-based fertilizers, and are equally effective in terms of crop uptake and yield, says Outotec.

The Ash Dec process has been demonstrated in a 7-m.t./d pilot unit operating between June 2008 and May 2010. The pilot plant, located in Leoben, Austria, treated the ash from Vienna and successfully produced nearly 1,000 tons of complex fertilizer. The process is commercially ready, says Hermann, and is economical for capacities of 30,000–32,000 m.t./yr, or smaller if integrated into a new sludge incineration facility.

Another thermal process is Mephrec (metallurgical phosphorus recycling), which is being developed by ingitec GmbH (Leipzig, Germany; www.ingitec.de). Mephrec takes place in an oxygen-blown, fixed-bed shaft ingitec

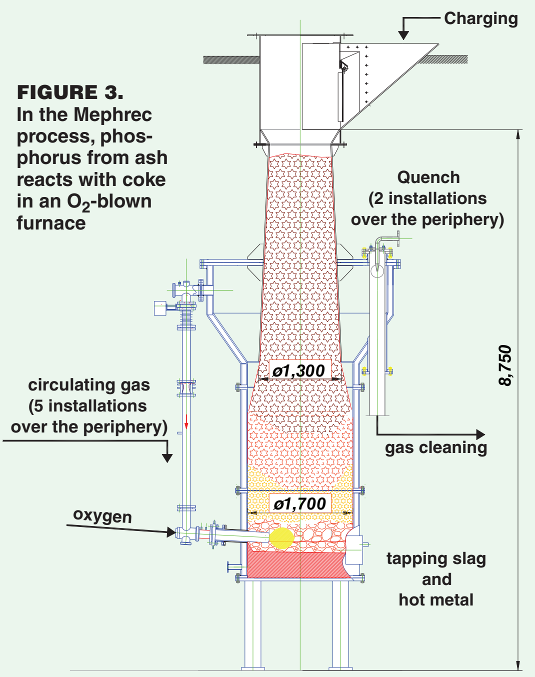


FIGURE 3. In the Mephrec process, phosphorus from ash reacts with coke in an O_2-blown furnace

furnace, with metallurgical coke used as the energy supply (Figure 3), explains consulting engineer Klaus Scheidig. Feed material is first agglomerated to ensure sufficient gas flow through the reactor. The briquettes are then fed at the top of the reactor and are heated as they pass down the reactor, countercurrent to the flow of hot gases. As they move downward, the briquettes are melted and gasified. Molten slag is tapped at the bottom at a temperature of about 1,450°C, then granulated with a water quench, resulting in a calcium-silico-phosphate with a high phosphorus-availability for plants.

Because Mephrec operates under reducing conditions, heavy-metal oxides are reduced to their metallic state, and either alloyed with the liquid-metal byproduct, or evaporated for subsequent recovery.

Another advantage of operating with O_2 is that the energy content of the sewage sludge is fully transferred to the offgas, and can be recovered for power generation. The accumulated revenues from power generation and the cost savings from sludge-disposal avoidance are sufficiently high to pay for the total recovery process, says Scheidig. As a result, the selling price of the product fertilizer is not a factor in the overall economic feasibility of the P-recovery process, he adds. A demonstration of the process is planned at a wastewater treatment facility in Nuremberg, Germany. The Mephrec plant will have a capacity of 12,000 m.t./yr when it starts up in 2013–2014. A future commercial unit will have a 70,000-m.t./yr capacity, says Scheidig.

Outotec and ingitec are also participants in the P-REX project, a three-year, €4.4-million research project under the European Commission's Seventh Framework Program (FP7). The project, which started in September 2012 and includes 15 partners from five countries, is said to be the first "holistic full-scale evaluation of the P-recovery techniques using municipal sludge or ashes in comparison with phosphorus recycling by land application of sewage sludge." It's looking at the complete life cycle, says Outotec's Hermann.

Another major E.U. project under the FP7 program is RecoPhos (www.recophos.org). Started in January 2012, the 36-month, €4.5-million project consists of a consortium of ten partners from six countries. The goal of the project is to develop a sustainable and highly efficient process to recover phosphorus from sewage-sludge ash.

RecoPhos is a thermo-chemical process involving the fractioned extraction of phosphorus and heavy metals. The chemical principle of the core reactor is the Wöhler process, whereby phosphates react with carbon and SiO_2 in a furnace, and is reduced to phosphorus. RecoPhos uses the InduCarb retort, where a coke bed is heated inductively, and the reduction of phosphates takes place in a thin melt film on the surface of the coke particles. The reduced phosphorus can be evaporated and recovered as either P_2O_5 or phosphoric acid.

The project aims to study the technology at the laboratory scale, along with modeling and simulation studies, which will provide the basis for the implementation of a fully operational bench-scale reactor and the design for a pilot-scale plant. ■

Gerald Ondrey

TAMING THE CPI'S ENERGY BEAST

Motors are notorious energy users, but advanced motor and drive technologies can help increase efficiency in the plant

Emerson Industrial Automation

FIGURE 1. The Dyneo LSRPM permanent-magnet synchronous motor's patented technology allows a significant increase in efficiency, particularly in machines that operate with a variable load

Baldor Motor

FIGURE 2. Baldor offers the power dense, energy efficient technology of the RPM AC motor with permanent-magnet rotor technology to provide a direct drive motor for cooling tower applications

Whether for pumping, mixing, compression or ventilation, motors are used everywhere in the chemical process industries (CPI). Unfortunately, they are notoriously energy intensive, accounting for about 65% of the electrical consumption of a chemical production site. However, with the world, especially the U.S. and Europe, turning a watchful eye on energy consumption, motor and drive manufacturers are developing newer, highly efficient motors, optimized systems and smarter drives that can help tame the proverbial energy beast, leading to potentially significant savings.

"We are finding that improvements in the efficiency of fixed-speed motors allow a reduction of approximately 10% of the electrical energy consumption of a site, while the use of variable speed generally allows savings of over 30% to be made on the drive system concerned," says Pascal Galant, president of sales and services for drives and motors with Leroy-Somer (Angouleme, France; www.leroy-somer.com), a business unit of Emerson Industrial Automation.

Among the latest offerings, according to Galant, are induction motors with IE2 or IE3 efficiency levels that can be used in conjunction with very low-loss gearboxes. For variable speed, motors specifically designed for operation on variable speed drives provide solutions for process requirements such as high efficiencies and operation at constant torque. And innovations including permanent magnets are also becoming more widely available. These technologies are making it possible to find the energy reductions stated above.

Advanced motors

For example, Leroy-Somer offers its Dyneo variable speed drive units, such as the LSRPM permanent-magnet synchronous motor (Figure 1). The LSRPM has the benefit of the mechanical construction of an induction motor, making it particularly suitable in harsh environments. But by eliminating rotor losses, the patented technology of the radial permanent-magnet rotor allows a very significant increase in the efficiency of the machines, in particular those that operate with a highly variable load.

The company says it has measured additional energy savings of over 10% compared with traditional variable-speed solutions (IE2 induction motors controlled by a variable speed drive).

Baldor Electric Co. (Ft. Smith, Ark.; www.baldor.com), a member of the ABB Group, is offering a cooling-tower direct-drive, permanent-magnet motor and variable-speed drive as a more energy efficient replacement for conventional mechanical-gear reduction designs. The cooling-tower drive controller and RPMAC permanent-magnet motors (Figure 2) are designed to drop directly into existing gearbox-mounting patterns. One of the biggest benefits of a retrofit is the improvement to the fan-drive-system efficiency via the elimination of the gearbox from the system and the addition of the adjustable-speed drive. Permanent-magnet motors greatly increase operating efficiencies, even under lightly loaded conditions that are typical in fan applications at low speeds. Temperature rise in the motor is also considerably lower, making for a power-dense package and increased motor life over conventional motor systems.

And, Hagglunds (Mellansel, Sweden; www.hagglunds.com), a division of Bosch Rexroth AG (Lohr, Germany), offers its CBM direct drive motor to help processors do more with less energy and resources, says Ashok Amin, mining and material handling manager in the Americas with Hagglands. The

THE EVOLUTION OF ENERGY MANAGEMENT

There's no question that energy management strategies will continue to be a linchpin of industry business strategies for years to come. But the ideal energy management program is a moving target, with new factors continuously coming into play.

Standards, such as the new ISO 50001 Energy Management System Standard, will shift the way processors identify and implement best practices in energy management. ISO 50001 established a framework to manage energy in facilities and benchmark achievements, and is estimated to influence up to 60% of the world's energy use. Based on a continual improvement framework, it supports organizations in their effort to develop and implement energy policies with established objectives, targets and action plans. When implemented effectively, ISO 50001 can help processors make better use of energy-intensive assets through benchmarking, measuring, documenting and reporting energy efficiency improvements and their projected impacts on reductions in greenhouse gas emissions.

To help address some of the measurement and reporting, Rockwell Automation is working with ODVA, the organization that supports network technologies built on the Common Industry Protocol (CIP) architecture, to develop an international energy standard based on CIP, called CIP Energy, which will offer processors a uniform method to measure, report and control energy consumption.

Energy management solutions

Industrial energy management solutions can help processors — no matter where they may be — in their energy management journey, manage their water, air, gas, electric and steam (WAGES) resources.

The first step is gaining awareness. Processors can use existing automation devices and systems to obtain much of the necessary WAGES data needed to understand consumption in a way that helps lower production costs and greenhouse gas emissions. Experts at Rockwell Automation suggest solutions that use CIP Energy to standardize the format of all energy data available throughout the automation system. Power quality monitors, smart motor controllers and other equipment can help with awareness issues.

Building efficiency is the next step. Processors can also make incremental and proactive behavioral, control and equipment improvements by leveraging the resource-consumption data. Improvements include forecasting, load aggregation and rate-analysis exercises, which can add dollars to the bottom line and increase competitive edge.

Optimization comes next. By modeling production with energy as an economic variable, processors can optimize their plant-floor assets. Merging the enterprise-wide WAGES data, including production metrics, regulatory reports, and behavioral and climate forecasts allows processors to balance process variables inherent to production. As a result, companies can increase profitability and improve the total cost of ownership of their operational assets, according to Rockwell Automation.

Finally, processors can compare consumption information against production output data and other enterprise-resource planning-level information to gain higher returns on their production bill of materials and enhance their supply chain to include energy as an output. ❑

FIGURE 3. **The PowerFlex 755 drive is suitable for a variety of applications ranging from simple variable-speed and variable-torque control to those requiring constant torque control**

CBM packs 50% more torque into a motor that is smaller and lighter than its predecessor, giving it the world's highest torque-to-weight ratio, yet maintaining the advantages of an efficient direct-drive motor. Full torque from zero, protection from shock loads and four-quadrant operation allow processors to handle more work with less space and less energy use, says Amin.

FIGURE 4. **D-Frame drives are optimized to deliver highly reliable performance while exhausting 90% of the drive-generated heat outside the enclosure via the backchannel**

New drive technology

Along with new motor designs, come new drive technologies. "We have to continue to add new capability to our drives, including the addition of control modes for new kinds of motors like permanent-magnet motors, so we can run on a broader array of motors as they find use in industry," says Douglas Weber, business development manager with Rockwell Automation (Milwaukee, Wis.; www.rockwellautomation.com).

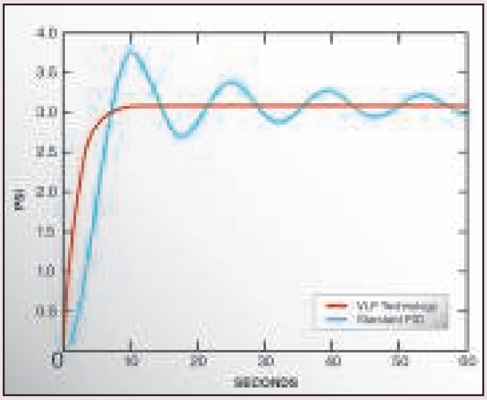
In addition, drive manufacturers are working to make their drives smarter, more capable and smaller. Rockwell's PowerFlex 755 (Figure 3) is a prime example. Not only does it provide interior permanent-magnet motor control, but it also provides more energy-measurement capability into the drive so the drive can report the energy usage of the drive and motor in that process to the control- and energy-management systems to give processors a better gauge as to where energy is being used in the plant. "By increasing reporting and communication capabilities, we are enabling processors to make production decisions based on energy usage as a variable. We call this 'energy on the bill of material' and it can be a powerful tool for chemical processors. It allows them to look at energy as a variable, not just a necessary cost," explains Weber (for more, see sidebar above, "The Evolution of Energy Management").

Danfoss Drives (Love Park, Ill.; www.danfoss.com) is working on putting expanded capabilities into a smaller footprint, says Patrick Appleby, vice president of sales for industry with Danfoss. What they've come up with is the new D-Frame VLT Drive (Figure 4), which is 68% smaller than previous-generation drives and optimized to deliver

SOLVING THE POWER EQUATION IN PUMP MOTORS

Process control via traditional adjustable-speed drives (ASD) with centrifugal devices has an inherent problem of attempting to use a linear equation to solve a non-linear problem. Traditional proportional integral derivative (PID) methods control frequency directly. Controlling frequency directly produces flows and pressures along a non-linear curve and an individual machine's impeller design.

Toshiba created VLP (Virtual Linear Pump) Drive Software to offset this issue. According to a white paper published by Toshiba, the pump industry improved the mechanical aspects of pump design through increasingly sophisticated computer CAD/CAM modeling and improved machining, and the use of ASDs achieved better energy efficiency as the kilowatt usage drops off along a voltage/frequency ratio. However, the aspect that was missing, which the Toshiba software addresses, was the ability to solve indirectly for power (*P*) in the Pump Affinity Laws for each machine, individually, whether the machine operates alone, in series or in parallel.



The new VLP algorithm provides enhanced control, expanded configuration options and improved energy efficiency over the conventional PID method

Toshiba

The VLP algorithm starts with a fixed VLP number, according to the white paper. If the output of the electrical current is less than the VLP number, the frequency is increased. Otherwise, if the output current is greater than the VLP number, the frequency is decreased. The frequency (in Hz) turns into rpm to meet the current draw (amp draw). This is true on centrifugal devices. Amp draw is linear to both pressure and flow, and non-linear to speed (*N*). This is in contrast to the VLP algorithm, which controls power directly to meet pressure or flow.

The VLP number is a percentage of available amps of power of a specific ASD. When a motor/pump is first setup in the VLP wizard, the user is instructed to enter the motor's full-load amps into the drive. The ASD temporarily sets the VLP Max variable to the entered motor amps divided by the ASD full output amps. The operator can then adjust the MAX VLP number to achieve the maximum desired set point for flow, pressure and so on. At this point, the ASD has sorted the limits of where the pump can operate. On multiple-pump systems, this is repeated so each machine has the same operational set points. The VLP numbers, which all effect the corresponding amp draw and frequencies of operation at any given point, will be different because of mechanical differences in piping, impeller wear or trim, and motor efficiency. Next, a Virtual Linear Pump curve is created in the software, where a percentage of each pump will run at the required power in order to precisely match the other pumps' set points.

If controlled from a common external analog signal, A VLP MIN of 0% will cause the pumps to run at the MIN VLP set point. The same is true at 100% where all pumps will be running at their individual MAX VLP. What is important is that for each change in set point, the resulting flow or pressure will be linear, whereas the frequencies and amp draws will be non-linear.

This is important on a single machine when the frequency is changed, as in standard ASDs the output is non-linear and energy is wasted searching to find the appropriate speed needed to satisfy the control loop. Because VLP produces a virtual linear performance curve, the first calculation from an external PID controller will most likely be the most accurate calculation. The VLP software changes the power of the motor to produce the desired pressure or flow. No time or energy is wasted accelerating and decelerating past the needed frequency.

This new VLP algorithm for the Toshiba P9 drive provides enhanced control, expanded configuration options and improved energy efficiency over the conventional PID method, according to the company's white paper. ❑

highly reliable performance in the 125- to 450-hp range, while exhausting 90% of the drive-generated heat outside the enclosure via the backchannel for high energy efficiency.

Also, to create more efficiency in pump motors, Toshiba International Corp. (Houston; www.toshiba.com) is offering its P9 low-voltage adjustable-speed drive. The drive incorporates Toshiba's proprietary Virtual Linear Pump (VLP) Technology, allowing the drive to linearly control pressure, temperature or flow (see the excerpt from a Toshiba white paper in the sidebar above, "Solving the Motor Power Equation in Pumps" for more on how this works).

"Every pump has a curve, a non-linear curve," says Kevin Nguyen, application engineer with Toshiba. "And, it's very hard to predict that curve using the linear equations of traditional PID (proportional integral derivative) programs and get the best efficiency from that pump. PID looks at the rate of error and compensates for it, which leads to overshooting, speeding up and slowing down until it eventually levels out to the correct pressure, flow or rate of speed. We set out to find a better method that would lead to more efficiency and came up with VLP, which helps increase the efficiency of the pump motor," he says.

Baldor Motor

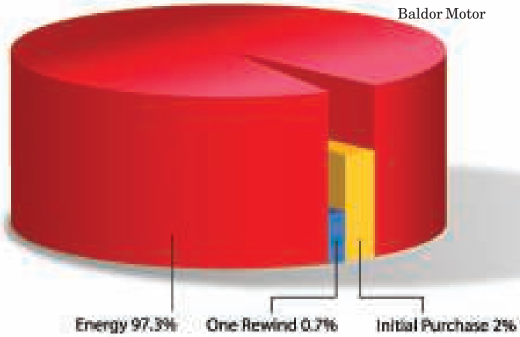


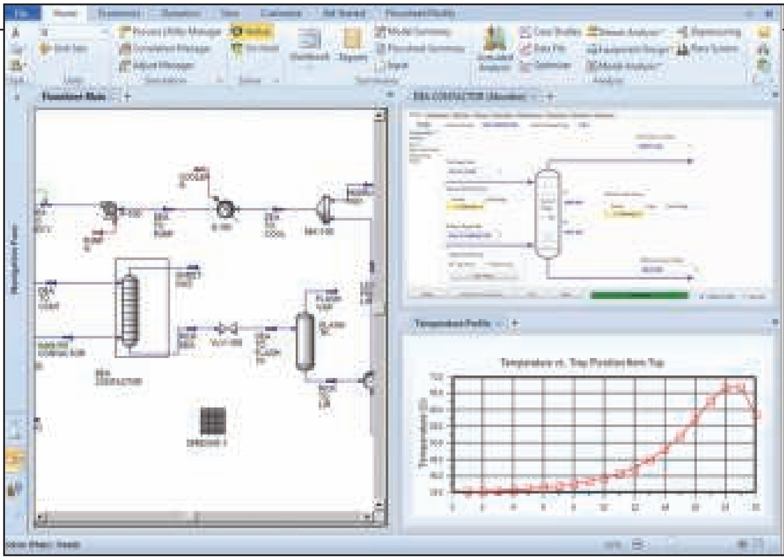
FIGURE 5. Investment costs for a motor are a small fraction of the total life cycle costs

Obviously these solutions come with a higher price tag than lower-efficiency, standard-induction motors, motor systems and drives, but like most things in life, you get what you pay for. For example, John Malinowski, senior product manager for AC motors with Baldor Electric Co., suggests looking at the bigger picture during a motor upgrade. "If you look at the pie chart of a motor's 20-yr life cost (Figure 5), you can see that the initial purchase price is only about 2%," he says. "Ninety-seven percent of the lifetime cost of a motor is the electricity used to operate it. Yes, you will pay more upfront for a premium motor, but you'll pay significantly more later for the electricity used to run a less efficient motor." ■

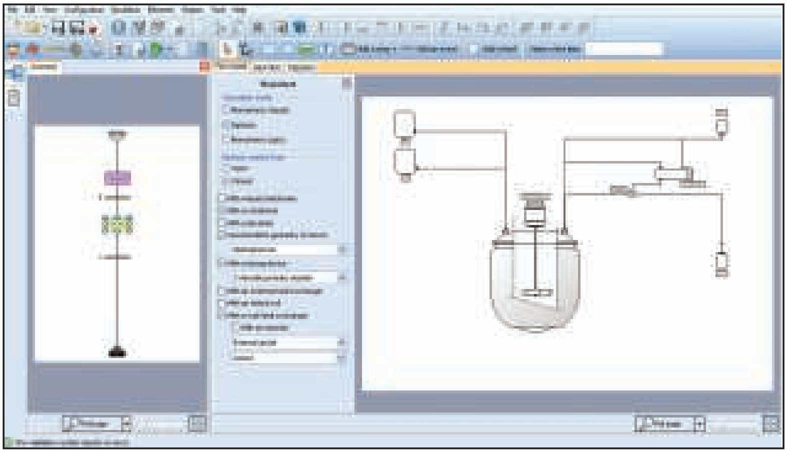
Joy LePree

FOCUS ON

Software



Aspen Technology



ProSim

This new software version includes solids modeling

The latest iteration of this company's process automation software, aspenONE V8 (photo), was recently released with new functionality, including solids modeling. The integration of the solids modeling capability eliminates the "silos" that previously existed between solid- and liquid-modeling processes. The aspenONE V8 software package delivers an updated version of the process simulator HYSYS, for generating process simulations in the hydrocarbons industry. The new HYSYS features a redesigned user interface and streamlined workflow. With its focus on usability, this company says new and occasional users of the software can become proficient more rapidly, and experienced users can do more. Version 8 of aspenONE also features an "activate" function, designed to help process engineers quickly identify ways to reduce energy through design alterations. — *Aspen Technology Inc., Burlington, Mass.*
www.aspentech.com

Combine equipment modeling and reaction engineering

BatchReactor (photo) is designed for the simulation of batch chemical reactors, and a new version of the software was released in the fourth quarter of 2012. The software combines equipment modeling with reaction engineering and advanced numerical methods, allowing specialty chemicals makers to test alternative synthesis routes and new production strategies. BatchReactor features an intuitive graphical interface, where the operating procedure is represented in a simple way, with a view of the sequence of process steps and a diagram of each step available on the same screen. The software also features a flexible and efficient thermodynamics package that relies on proven numerical methods, the company says. — *ProSim SA, Labège, France*
www.prosim.net

Metso Automation USA

This valve-sizing software has new calculation modules

The new version of this company's Nelprof 6 expert valve-sizing software (photo) that has been released extends earlier versions with two new calculation modules that can help users select intelligent automated on/off valves and emergency valves. With the tools in the new version of the program, special safety requirements, such as an actuator-sizing safety factor or a complete valve-assembly safety-integrity level, can be evaluated. The Nelprof 6 control-valve sizing software helps reduce engineering time and improves the selection accuracy, the company says, because the calculations are based on real-world data collected from the field over several decades. The easy-to-use software allows users to avoid significant sizing errors while streamlining the process, the company adds. — *Metso Automation USA Inc., Norcross, Ga.*
www.metso.com

Note: For more information, circle the 3-digit number on p. 60, or use the website designation.

A workflow approach guides non-experts with this software

This company's new multivariate-analysis software program, called Insight, is designed to provide the full capability of modern chemometrics without requiring specialized training. Insight's model builder employs a step-by-step workflow approach to guide users in assembling the data needed for building and evaluating calibrations. The company notes the resulting calibrations are fully validated and ready for deployment. The entire Insight package has been developed from the ground up to provide a natural, non-intrusive development environment that frees the user to focus directly on meeting project requirements without worrying about menu trees, keystroke sequences, or software syntax, says the company. The Insight family of software products can be used for laboratory and process analysis. — *Symbion Systems Inc., Tustin, Calif.*
www.gosymbion.com

This product allows remote control of operations

The AutoLog ControlMan allows remote monitoring and control of processes, machines, devices, valves, pumps, unmanned stations and other equipment. The scalable and flexible system uses existing global-communication networks to monitor assets cost effectively. With ControlMan, measurement data are sent wirelessly, and users can log in to the service through an Internet network and can use a conventional Web browser on any Web-connected computer. The system gives access to dynamic maps, measurement trends, alarm views, animated process views, reports and more. — *FF Automation Oy, Vantaa, Finland*
www.ff-automation.com

Performance monitoring added to this sorting software

New performance-monitoring enhancements have been added to this company's I-watch sorter maintenance software. The upgrade allows this company's technicians to complete regular, remote analyses of machine performance and condition information for the company's sliding shoe sorters. The software now transmits 145 sorter-performance data points each day — including wear characteristics, operational statistics, as well as maintenance alarms and events — to this company's customer service team. Technicians from the company review the data to identify abnormalities, quickly diagnose and resolve problems, and advise customer maintenance teams on steps to maximize system utilization and extend sorter life. — *Intelligrated, Cincinnati, Ohio*
www.intelligrated.com

Explore large data sets with this software

Unscrambler X multivariate analysis software is designed to help engineers explore large, complex data sets and better understand processes. — *Camo Software AS, Oslo, Norway* ■
www.camo.com

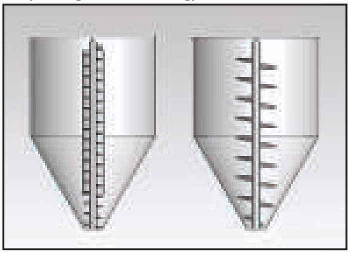
Scott Jenkins

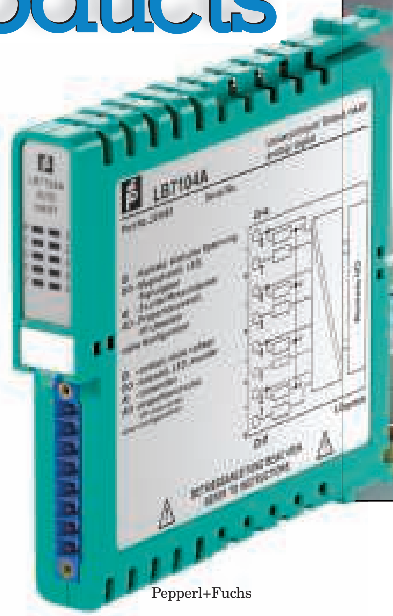
Sartorius Stedim Biotech

FEBRUARY New Products

Lee Products

Kreyenborg Plant Technology





Pepperl+Fuchs

This little valve has a zirconia ball and seat

The new Hard Seat VHS Micro-Dispense Valve (photo) offers repeatable, non-contact dispensing of fluids in the nano- to microliter range. It features a precision zirconia ball and seat instead of a traditional elastomeric seal, thereby ensuring resistance to aggressive fluids, such as dimethyl sulfoxide. The valve is designed for two-way, normal closed operation, and the wetted parts comprise stainless steel, polyether ether ketone (PEEK) and zirconia. — *Lee Products Ltd., Gerrards Cross, Bucks, U.K.*
www.leeproducts.co.uk

A compact flowmeter that has no moving parts

Mag-View (photo) is a compact, high-quality, yet economical, device for measuring liquid flowrates in applications where flow sensors with moving parts cannot be applied. Its interference-free operation, combined with a long lifecycle and independence from the inlet and outlet pipework makes it suitable for use in compact machines and installations. It can be used for both continuous and batch or dosing applications. Mag-View operates on the magnetic inductive principle, and is therefore suitable for electrically conductive liquids with a minimum conductivity of 50 µS/cm. Three models are available with flowrate ranges of 1–20, 2–40 and 10–200 L/min. — *Mass Flow Online B.V., Ruurlo, The Netherlan*
www.massflow-online.com

Slash silo mixing times with this open mixing screw

A company in Hamburg, Germany had been using a 20-m^3 mixing silo with internal pipe auger for 20 years. By replacing the pipe auger (photo, left) with an open mixing screw with special segments (photo, right), the company gained a better mixing result in a shorter mixing time (20 min instead of 4 h) and was able to drastically reduce the energy consumption of the mixer, says the manufacturer. This result is based on plastic regrind, but the mixing technology is suitable for all free-flowing materials. — *Kreyenborg Plant Technology GmbH & Co. KG, Münster, Germany*
www.kreyenborg-pt.de

Compact remote I/Os save space and the cost per channel

Four-channel analog I/O modules can be placed in a 16-mm-wide enclosure due to a new energy-saving electrical design. This results in a space savings of 50% compared to the predecessor model, says the company. The new design reduces the cost per channel by using smaller control cabinets. The new four-channel universal I/O module LB7104A (photo) is equipped with a status LED for fast diagnostics. The universal I/O module is also able to operate as an analog input or analog output (4–20 mA). It can also be used as a digital input (On > 1.2 mA; Off > 2.1 mA) or digital output (12 V; 25 mA). The respective settings can be adjusted in the Device Type Manager for each channel. — *Pepperl+Fuchs GmbH, Mannheim, Germany*
www.pepperl-fuchs.com

Mass Flow Online

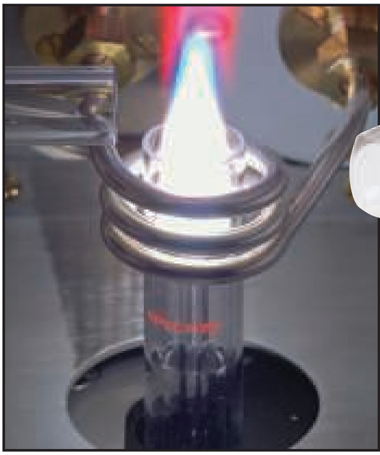
PES nanofleece prefilters for the biopharmaceutical industry

The newly launched Sartoguard NF prefilter series (photo) feature a unique combination of high-performance polyethersulfone (PES) membranes and nanofleece technology. This is said to be the first time that PES nanofleece material is being used for liquid prefiltration applications in biopharmaceu-

Note: For more information, circle the 3-digit number on p. 60, or use the website designation.

tical manufacturing. The nanofleece technology provides an ultrafine fleece structure based on small (120–150-nm dia.) nanofibers compared with conventional fleece materials of more than 500-nm dia. The resulting fleece structure offers enhanced clarification capabilities, even for extremely fine contaminants, along with a high dirt-holding capacity, fast flowrates and high total throughput performance, says the company. — *Sartorius Stedim Biotech, Göttingen, Germany and Aubagne, France*
www.sartorius.com

Increasing the sensitivity of trace-element analysis
By using electrothermal vaporization (ETV) for sample introduction, this company has greatly improved the sensitivity of its Arcos ICP-OES spectrometer (photo) for material-analysis applications. Trials verify that detection limits can be improved by an order of magnitude. At much lower cost, ICP-OES penetrates the sensitivity range of glow-discharge sector field mass spectrometers, opening a new application area in solid material



Spectro Analytical Instruments

analysis for ICP-OES. Typically, ICP-OES samples are first dissolved and then introduced into the instrument using a nebulizer. With ETV, however, the solid samples are vaporized in an oven at temperatures of up to 3,000°C. The graphite vaporization chamber uses argon as the inert gas. After vaporization, the analyte is transported as a dry aerosol to the ICP instrument with an Ar/reaction-gas stream. Sample vaporization takes just 2 min. — *Spectro Analytical Instruments GmbH, Kleve, Germany*
www.spectro.com

WIKA Alexander Wiegand

A temperature sensor designed for pipe surfaces
The TF44 sensor (photo) is designed for measuring the temperature on pipe surfaces. The small design of the protective sleeve enables optimized mounting of the sensors and the insulation above them, even on pipelines with a small nominal width. The thermowell material is aluminum, which provides the best possible thermal transfer from the medium to the measuring element, says the company. The choice of measuring elements is between Pt1000 and Pt100, in addition to NTCs and other custom-made solutions. Connection cables, from silicone or polyvinyl chloride (PVC) are

assembled in user-specified lengths. — *WIKA Alexander Wiegand SE & Co. KG, Klingenberg, Germany*
www.wika.com

This syringe pump delivers continuous, smooth flow
Designed for flow chemistry applications, the patented Asia Syringe Pump (photo, p. 31) is said to give users a tool for performing flow reactions not possible using HPLC pumps or "single-shot" syringe pumps. Used in combination with the Asia Pressurized Input Store, the Asia Syringe Pump takes advantage of positive input pressure to deliver continuous, extremely smooth flow — from 1 to 10 µL/min — at pressures of between 0 and 20 bars, while minimizing outgassing and cavitation, says the company. The pump can be used independently, or as a component of the Asia Flow Chemistry system. — *Syrris Ltd., Royston, U.K.*
www.syrris.com

See more with this new generation of spectroscopy software
AvaSoft 8.0 is the latest generation of this company's spectroscopy software. This totally new application features multi-monitor displays and multiple simultaneous measurements. The Windows-based software for miniature, fiber-optic spectrometers also includes a completely redesigned, more user-friendly graphic-user interface. Users of previous versions of AvaSoft can upgrade to 8.0 free of charge until March 31st. — *Avantes B.V., Apeldoorn, The Netherlands*
www.avantes.com

Three new digital displays for your measured values
The Afriso DA 10, 12 and 14 digital display units (photo, p. 30) are suitable for displaying measured values and evaluating and controlling standard signals (4–20 mA, 0–1 and 0–10 V) from electronic transducers, especially in level applications. The connected transducer is supplied with galvanically isolated 20-V d.c., while the measuring input can be configured as a current or a voltage input. The user interface with selectable display languages (English, French, German or Italian) ensures fast commissioning, says the company. Bearing charts for all cylindrical, horizontal and spherical tanks are preprogrammed. Depending on the device version, the units handle up to four voltage-free relay outputs as limit switches (for pumps and valves, for example) and two galvanically isolated analog

Afro-Euro-Index

Vega Grieshaber

Syrris

outputs. — *Afro-Euro-Index GmbH, Güglingen, Germany*
www.afriso.de

This vibrating level switch handles extreme conditions

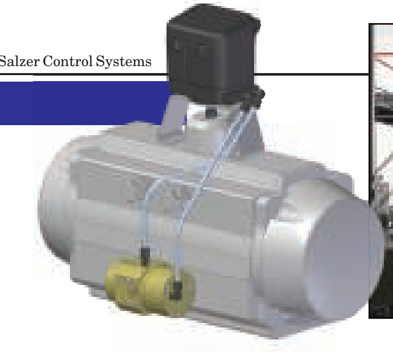
Until now, the principle of a vibrating level switch has been limited to process conditions up to a maximum of 280°C and 100 bars. By using a new drive for the tuning fork of its Vegaswing 66 (photo), this company has made it possible to operate over the temperature range from –196 to 450°C and pressures from 0 to 160 bars. The integrated analysis and monitoring capabilities allow certification according to SIL2 and steam boiler regulations. The application range extends from distillation columns in the oil-and-gas industry, to high- and low-water limits in steam boilers, and cryogenic applications in gas tanks for LNG and nitrogen. — *Vega Grieshaber KG, Schiltach, Germany*
www.vega.com

A new anionic surface-sizing agent

Basoplast 450 P is a new and highly cost-efficient polymeric surface-sizing agent (PSA) for the packaging sector. The product is suited for linerboard grades and complements the manufacturer's range of anionic PSA in the graphical paper market. By replacing cationic PSA in packaging with Basoplast 450 P, paper manufacturers can now adjust the desired coloration on the surface with direct dyes, which can provide a more cost-efficient solution than incumbent systems, says the company. The new anionic PSA shows no foaming tendency nor sensitivity to pH or starch type, and can be used in both size or film press. — *BASF SE, Ludwigshafen, Germany*
www.basf.com

Control valves operate four times faster with this volume booster

With the newly developed, high-precision 4090 pneumatic volume booster (photo, p. 32) it is possible to amplify the air strength of the set point signal from the positioner to the actuator such that these control valves (depending on the nominal valve size) operate up to four times faster without further modification. The pneumatic volume booster is based on a diaphragm system with which


Schubert & Salzer Control Systems


Michell Instruments

the pressure and volumetric flow of the control air are increased up to 6 bars through the controlled input of supply air. In the volume booster, the control air is fed through an adjustable bypass to the actuator. By controlling the flowrate in the bypass, the switching threshold for activating the amplifying air can be controlled precisely. The 4090 pneumatic volume booster enables significant reductions in switching times. — *Schubert & Salzer Control Systems GmbH, Ingolstadt, Germany*
www.schubert-salzer.com

Accurate RH & temperature measurement in harsh environments
To best meet specific application needs, the DT722 relative humidity (RH) and temperature transmitter (photo) is available in digital (DT722) and analog (DT722-X18) models. The digital version gives high performance measurement with "excellent" RH accuracy and delivers reliable, consistent and accurate results, even over changing ambient conditions, says the company. The DT722-X18 is an analog through-path measurement device with exceptional mechanical toughness. DT722 transmitters have stainless-steel housings for protection against rough handling or accidental damage, IP65 (NEMA 4) ingress protection and a probe that can withstand temperatures up to 150°C. — *Michell Instruments Ltd., Ely, U.K.*
www.michell.com

Phthalate-free tubing for food and beverage applications
Tygon S3 (safe, smart and sustainable) is said to be the first bio-based and phthalate-free tubing, and is the next generation of flexible tubing from this company for food and beverage manufacturers. Tygon S3 complies with FDA, NSF and 3-A requirements for food-and-beverage applications, as well as with Japan Food Sanitation Law # 370/1959. It also complies with European regulations (10/2011/EU) for many food-and-beverage applications when used as instructed. Tygon S3 uses a bio-based plasticizer instead of phthalates to provide "exceptional durability and longevity," says the company. — *Saint-Gobain Performance Plastics, Akron, Ohio*
www.processsystems.saint-gobain.com ■

Gerald Ondrey

CHEMICAL ENGINEERING
FACTS AT YOUR FINGERTIPS
Department Editor: Scott Jenkins

Steam-System Water Preparation

Supplying steam that meets process needs while protecting steam-system components, such as boilers and steam turbines (Figure 1), against scale, fouling and corrosion, requires purified feedwater (condensate plus makeup water). Depending on the steam pressure required, the specific approach of the water treatment may be shifted to account for a variety of issues. For example, caustic corrosion and phosphate corrosion of boiler tubes are rare in boilers operating below 1,000 psi, but become more of a threat as operating pressures rise above that level. The following outlines water treatment requirements at different steam pressures and some of the important reactions at high- and low-pressure ranges.

Low-pressure steam systems

At steam pressures below 600 psig (41 bars), boiler feedwater is treated to prevent hard scale formation and corrosion in the boiler. Raw makeup water or heat-exchanger-cooling water from a lake or river typically contains several hundred ppm of cations and anions, most notably calcium, sodium, magnesium, potassium, bicarbonate, chloride, silica, and sulfate, as well as other materials, including suspended solids. As these contaminants enter the boiler, a number of temperature-induced reactions will occur. Two common scale-forming reactions are shown below.

$$Ca^{+2} + 2HCO_3^{-1} \longrightarrow CaCO_3\ (s) + CO_2\ (g) + H_2O \quad \textbf{(1)}$$

$$Ca^{+2}\ (\text{or } Mg^{+2}) + SiO_3^{-2} \longrightarrow CaSiO_3\ (s)\ (\text{or } MgSiO_3\ (s)) \quad \textbf{(2)}$$

Even a relatively thin deposit will significantly reduce heat transfer, and a boiler must be fired harder to achieve the same level of steam production. This in turn can lead to overheating of the boiler tubes, which will shorten tube life.

Some type of chemical addition, such as phosphate addition, is used together with gross particulate filtration and decarbonation. For decades, steam-generation chemists have utilized sodium phosphate compounds for corrosion control and prevention of solids deposition in the waterwall circuits of drum-type, steam-generating systems. Alternatives are also available, but can be tricky to control. Boiler water salts are kept from the steam cycle by control of the entrainment carryover and by boiler blowdown.

Medium-pressure steam systems

With steam pressures of 600 to 2,400 psig (41 to 165 bars), control of silica, control of corrosion, and removal of particulate matter are required. Control of silica is necessary to prevent silica from volatilizing with the steam and depositing on the turbine blades. Makeup feedwater demineralization with an anion bed can control the silica levels in the water if it cannot be controlled economically with boiler blowdown. Control of corrosion is mainly done by adding phosphates or using all volatile treatment (AVT). AVT uses ammonia or other volatile amines (morpholine, monoethanolamine) to adjust water pH and control corrosion in that way. Condensate "scavenging" is often used to remove corrosion products from condensate returning from the turbine. Condensate scavenging uses a cation-resin deep bed operated in the sodium or amine form to filter particulate matter and to remove all hardness ions.

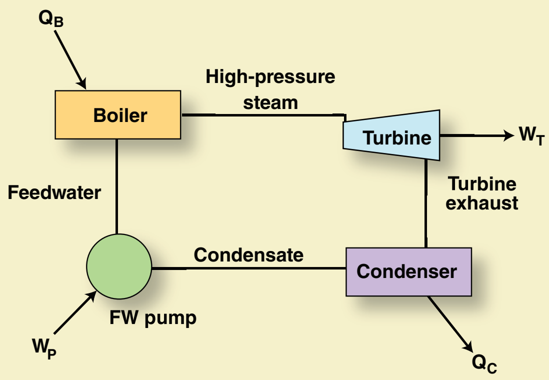


FIGURE 1. A basic steam generation system with isentropic turbine

High-pressure steam systems

As the boiler pressure increases beyond 2,450 psig (169 bar), demineralization of makeup water of the major contaminant ions, such as sodium and silica, becomes mandatory to satisfy the water quality requirements. Chemical treatment of the boiler or steam-generator system shifts from phosphate treatment to the use of AVT using ammonia or amines to elevate pH and control corrosion in the high-temperature and wet-steam areas of the steam-condensate loop. The optimum pH range depends on the materials of construction; at least 9.3 for all-ferrous systems and 8.8–9.2 for systems containing copper. For high pressure boilers, full-flow condensate polishing is a critical operation for the removal of soluble and insoluble corrosion products, and for the removal of contaminant ions as a result of a condenser in-leakage.

In North America, pressurized-water-reactor (PWR) plants using recirculating-type steam generators (RSGs) have focused their secondary cycle, water-chemistry program on the minimization of insoluble-corrosion-product transport and sodium-to-chloride molar ratio control in the tubesheet crevice areas of the steam generator. A shift to the use of organic amines (monoethanolamine in most cases) for pH control and procedural changes in the resin-regeneration process have been instrumental in achieving the desired improvements in secondary-cycle water chemistry. In addition to AVT chemistry, hydrazine is added to scavenge trace amounts of dissolved oxygen and maintain reducing conditions. Operators must be cognizant, however of the role of oxygen scavengers in flow-accelerated corrosion. Hydrazine reacts with oxygen according to the following equation:

$$N_2H_4 + O_2 \longrightarrow 2H_2O + N_2\ (g) \quad \textbf{(3)}$$

Corrosion

At pressures of at least 1,000 psig or higher, the effect of cooling-water leakages into the system and their effect on rapid corrosion become more pronounced. The reaction shown below is a prime example.

$$MgCl_2 + 2H_2O \longrightarrow Mg(OH)_2\ (s) + 2HCl \quad \textbf{(4)}$$

A product of this reaction is hydrochloric acid, which may cause general corrosion by itself, but, when concentrated under deposits, the acid reacts with iron to generate hydrogen. In this mechanism, hydrogen gas molecules, which are very small, penetrate into the metal wall and react with carbon atoms in the steel to generate methane:

$$2H_2 + Fe_3C \longrightarrow 3Fe + CH_4\ (g) \quad \textbf{(5)}$$

Formation of the gaseous methane and hydrogen molecules causes cracking in the steel, greatly weakening its strength. Hydrogen damage is very troublesome because it cannot be easily detected.

References

1. Buecker, Brad, CPI Water and Steam Chemistry, *Chem. Eng.*, Feb. 2008, pp. 30–34.
2. Wolfe, Thomas, Boiler-water treatment: At high temperatures, the rules change, *Chem. Eng.*, Oct. 2000, pp. 82–88.
3. Aerts, Peter and Tong, Flora, Strategies for Water Reuse, *Chem. Eng.* Sept 2009, pp. 34–39.

Editor's note: Content for this "Facts At Your Fingertips" was taken from the three articles listed in the reference section.

CHEMICALS & PETROCHEMICALS
PETROLEUM REFINING
STONE, CLAY, GLASS & CERAMICS
NONFERROUS METALS
PULP & PAPER
FOOD & BEVERAGES
RUBBER & ELASTOMERS
4th Annual
CHEM|NNOVATIONS
CONFERENCE & EXPO
SEPTEMBER 25 – 26, 2013
GALVESTON, TX
MOODY GARDENS
CONVENTION CENTER
PRESENTED BY
CHEMICAL ENGINEERING
Interested in Exhibiting/Sponsoring?
Contact Carley Ziober,
713.343.1884 or
CarleyZ@tradefairgroup.com
Interested in Speaking?
Contact Cassie Davie,
713.343.1891 or
CassieD@tradefairgroup.com
www.cpievent.com

Technology Profile

Propylene Production via Propane Dehydrogenation

By Intratec Solutions

Because natural gas supplies are significantly increasing due to the rising exploitation of shale gas, mainly in the U.S., propane prices are decreasing. Coupled with low propane prices, ethylene producers are shifting to lighter feedstocks (more ethane, less naphtha), which is decreasing yields of propylene in cracking operations. The increasing demand for propylene and the availability of low-cost feedstock make propane dehydrogenation an economically attractive chemical route.

Propane, the main feedstock for propane dehydrogenation (PDH) processes, can be obtained as a byproduct of petroleum refinery operations and can be recovered from propane-rich liquefied petroleum gas (LPG) streams from natural-gas processing plants.

The PDH process

PDH is an endothermic equilibrium reaction. The PDH process depicted below is similar to the Oleflex process developed by UOP LLC (Des Plaines, Ill.; www.uop.com), and is suited to produce polymer-grade (PG) propylene from propane. The maximum unit capacity is around 650,000 ton/yr. This process is carried out in the presence of a platinum catalyst and achieves overall propylene yields of about 90 wt.%.

The industrial plant can be divided into two main sections: reaction and product recovery.

Reaction. In the reaction section, after heavy impurities removal in the de-oiler column, propane is sent to the dehydrogenation reactors. The propylene yield in such reactors is favored by higher temperatures and lower pressures. However, temperatures that are too elevated will promote thermal cracking reactions that generate undesirable byproducts. Therefore, the PDH reaction usually occurs at temperatures of about 650°C and near atmospheric pressures.

In order to purge the coke accumulated on the catalyst surface during the reaction, a continuous catalyst regenerator (CCR) unit is required. The catalyst circulates in moving beds through the reactors, before being fed to the CCR unit, which operates independently of the reaction, burning off the coke and returning the catalyst to its reduced state.

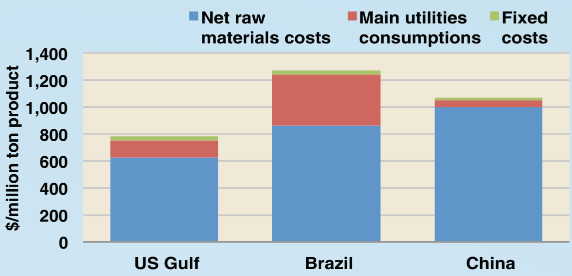
Product recovery. The reactor effluent is compressed, dried and sent to the product recovery section. In this section, a hydrogen-rich stream is recovered and light hydrocarbons and hydrogen traces are removed in a de-ethanizer. The PG propylene product is further purified in a propane-propylene (P–P) splitter and leaves as the top product.

Economic performance

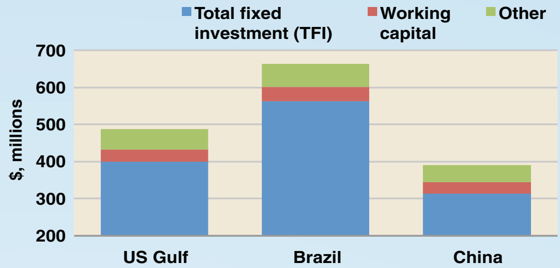
An economic evaluation of the process was conducted based on data from the second quarter of 2012. The following assumptions are assumed for the analysis:

- A 550,000 ton/yr PDH unit erected inside a petrochemical complex (all equipment represented in the simplified flowsheet below)
- No storage of feedstock and product is considered
- Net raw materials cost is the difference between propane and catalyst make-up costs and credits from fuel and electricity generated in the process

Regional cost comparison



Total capital investment



Global perspective

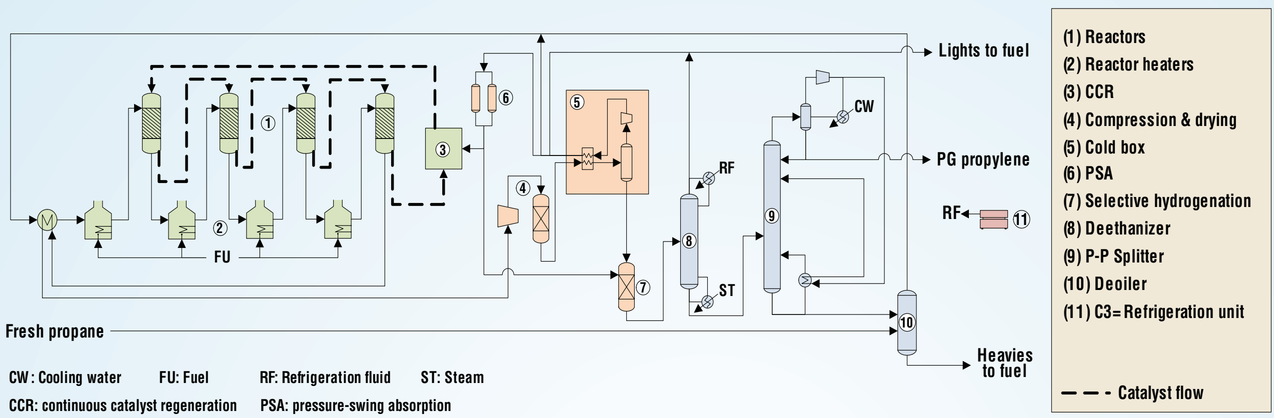
Recently, conditions in the U.S. have led to the lowest production costs and the most attractive EBITDA (earnings before interest, taxes, depreciation and amortization) margins (about 30%), due to the availability of low-cost propane derived from shale gas. Low-cost propane imported from the Middle East allows China to present favorable EBITDA margins of about 20%. The optimism about this process is demonstrated by the recently announced plans for at least six PDH units in China.

Considering the capital-cost requirements presented and an operating rate of 91%, the internal rate of return is above 30% in the U.S. and about 20% in China.

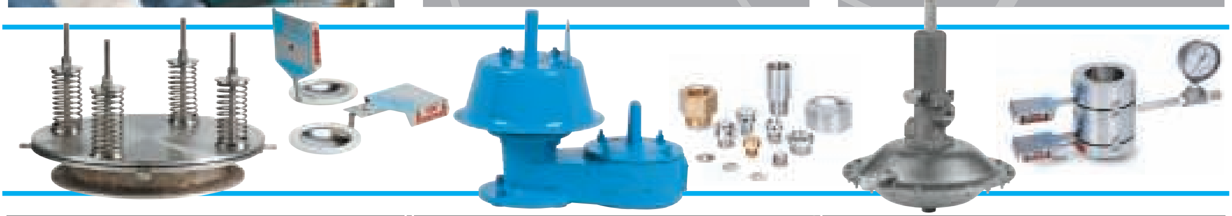
On the other hand, South America and Europe do not offer favorable conditions for PDH units. ■

Edited by Scott Jenkins

Editor's Note:
The content for this column is supplied by Intratec Solutions LLC. (Houston; www.intratec.us) and edited by *Chemical Engineering*. The analyses and models presented herein are prepared on the basis of publicly available and non-confidential information. The information and analysis are the opinions of Intratec and do not represent the point of view of any third parties. More information about the methodology for preparing this type of analysis can be found, along with terms of use, at www.intratec.us/che.





Cover Story

Sizing Calculations for Pressure-Relief Valves

A universal mass-flux equation can improve sizing calculations for pressure-relief valves with non-ideal fluids

Jung Seob Kim
SK E&C USA Inc.

Heather Jean Dunsheath
Bayer Technology Services

Navneet Radheshyam Singh
Bayer CropScience LP

Pressure-relief valves are widely and effectively used in situations where the pressure in a process vessel rises to above the vessel's design-pressure rating. Proper relief-valve sizing is critical to plant and process safety to permit fluids sufficient flow area to exit the vessel. Sizing relief valves requires several equations for different flows (liquid flow, vapor flow and two-phase flow), as well as two flow conditions (critical and sub-critical). Although the equations are similar, only one simple equation is required for a single-phase liquid, while a compressible fluid requires two equations — one for critical flow conditions and another for sub-critical flow conditions.

Emergency relief system designers use a variety of mass-flux equations to properly size relief valves [*1–4*]. A careful look at all the existing equations can yield insights on how the calculations can be executed with a single mass-flux equation. This article presents a universal mass-flux equation that can be used to easily and accurately size relief valves for liquid flow, vapor flow and two-phase flow at both critical and sub-critical flow conditions.

Existing methods

The simple mass-flux calculation methods of the American Petroleum Institute (API; Washington, D.C.; www.api.org) have been widely used in petroleum refineries and other industries [*1*]. Emergency relief system designers generally prefer these simple equations when sizing relief valves, but they are not accurate for highly non-ideal fluids. The API relief-valve-sizing methodology recently included a numerical integration method based on numerous isentropic flash calculations.

In addition to the API sizing calculations, the method put forth by the Design Institute for Emergency Relief Systems (DIERS; part of AIChE) for the integral form of nozzle flow has also been standard for sizing two-phase flow [*2*].

Determining the theoretical mass flux generally requires taking the variation in specific volume into account by integrating the pressure-volume correlation from the stagnation pressure (P_0) to the relief-valve-nozzle throat pressure (P). The flow through the ideal nozzle is adiabatic and frictionless, and the fluid velocity increases as the pressure of the fluid decreases to the system back-pressure.

As a fluid flows through a nozzle, the specific volume and kinetic energy increase. Therefore, the mass-flux model for nozzle flow requires that specific volume variations be taken into account. For incompressible flow, the fluid specific volume is almost constant, so the change in specific volume is negligible. For compressible flow, on the other hand, the change is significant. For flashing two-phase flow, non-equilibrium conditions exist and equilibrium flashing conditions are not achieved within the relief valve nozzle [*5–6*]. The actual changes are very difficult to predict. Therefore, the homogeneous equilibrium model (HEM) is currently considered to be the most appropriate for relief valve sizing because this model yields a conservative design.

UNIVERSAL EQUATION

The universal mass-flux equation for sizing relief valves is based on a specific set of assumptions. Any change during an expansion process will be within the assumptions. The assumptions are the following:

- Flow is steady from a large reservoir
- Flow is one-dimensional (that is, the flow properties within any cross-

section of the flow passage remain constant)

- The expansion process is isentropic
- Potential energy change is negligible
- The flow is in thermal equilibrium
- The flow is homogeneous

The mass flux for ideal nozzle flow is determined by Equation (1) where the integration is performed from the stagnation pressure (P_0) to the nozzle throat pressure (P)[*1*]. Determining the mass flux requires only a local specific volume at the nozzle throat and an average specific volume between P_0 and P. Thus, estimating the specific volumes during an expansion process is an essential part of the mass-flux estimation.

$$G^2 = \frac{-2\int vdP}{v^2} \qquad (1)$$

Equation (2) is a universal mass-flux equation, which is similar to the omega method for critical flow [*1*].

$$G = 68.07\sqrt{\frac{P_{ec}^{\ \beta+1}}{\alpha\beta P_0^{\ \beta} v_0}} \qquad (2)$$

where:

$$P_{ec} = \left[-2\alpha\beta P_0^{\ \beta}\left(\alpha\left(\frac{P_0}{P}\right)^{\beta} - \alpha + 1\right)^{-2} \times \left(\frac{\alpha P_0^{\ \beta}}{1-\beta}\left(P^{1-\beta} - P_0^{\ 1-\beta}\right) + (1-\alpha)(P-P_0)\right)\right]^{\frac{1}{\beta+1}} \qquad (3)$$

The universal mass-flux equation is derived based on Equations (1) and (4) and a pressure-specific volume correlation of Equation (5), which is the most accurate of the pressure-specific volume correlations presented by Simpson [*7*]. The pressure-specific volume correlation significantly simplifies mass-flux calculations. The two parameters α and ß in Equation (5) can be obtained from the pressure and specific volume data.

$$G_c^{\ 2} = \frac{-dP}{dv} \qquad (4)$$

$$\frac{v}{v_0} - 1 = \alpha\left[\left(\frac{P_0}{P}\right)^{\beta} - 1\right] \qquad (5)$$

Once these two parameters are available, Equation (2) can be readily evaluated to calculate the mass flux (G) through an ideal nozzle. However, it requires the equivalent critical pressure P_{ec}, which is defined as a function of pressure, physical properties and flow conditions. The universal mass-flux equation can predict mass flux for any fluid (liquid, vapor or two-phase) at any condition (critical and sub-critical) except flashing flow of initially sub-cooled liquid [*8*].

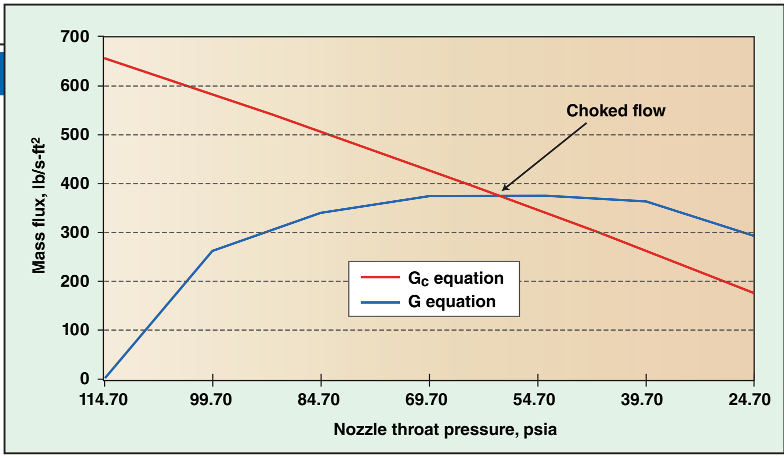


FIGURE 1. Maximum theoretical mass flux occurs at the intersection of G and G_c

The equivalent critical-pressure term makes it possible to predict mass flux for critical flow conditions as well as sub-critical flow conditions. When calculating P_{ec} using Equation (3), P should be less than P_0. If the calculated P_{ec} is less than P, the flow is at sub-critical condition and the mass flux is predicted with the calculated P_{ec}. However, if the calculated P_{ec} is greater than P, the flow is at critical conditions, and a few iterations are necessary to determine the critical pressure that is achieved when the calculated P_{ec} is equal to P. The initial P value can be 50% of P_0. The resulting calculated P_{ec} value will be the new trial P value. This iteration is repeated until P_{ec} is sufficiently close to P, which usually converges quite rapidly. The maximum mass flux for the given flow conditions is achieved at the choked pressure, which must occur when P_{ec} is at a maximum.

A graphical demonstration of the choked-flow conditions for the superheated air (see second example) is shown in Figure 1. The maximum theoretical mass flux is determined by the point of intersection of graphs G and G_c. The choking flow occurs at the intersection point. For an unchoked flow case, the mass-flux line (horizontal line) of 200 lb/s-ft^2 in Figure 1 intersects with the two graphs of G at 106.6 psia and G_c at 28.6 psia. This means that the mass flux by integration of the G equation from 114.7 psia to 106.6 psia can also be determined from the G_c equation at the equivalent critical pressure of 28.6 psia. It is likely that any equivalent mass-flux point with the G graph can be found on the G_c graph between the critical pressure and zero pressure.

Mass flux with one data point

The one-data-point method is very popular and preferred to more data points because it is simple and easy to apply. For special fluids, this method is the only option since the fluid properties at several points are not readily available. Generally, the one-data-point physical properties are in the larger reservoir. It is assumed that the fluid is at zero velocity (stagnation conditions) in the reservoir. Since this method involves significant extrapolation, the mass-flux prediction is inaccurate for highly non-ideal fluids.

For liquid flow, the physical properties, particularly the specific volume, are almost constant during an expansion process. The liquid-specific volume is nearly independent of the fluid pressure. Therefore, the mass-flux prediction with one data point is highly accurate. The two parameters for liquid flow are:

$$\alpha = \frac{0.00031}{\left(\frac{P_0}{14.7}\right)^{\beta} - 1} \qquad \beta = 0.00001 \qquad (6)$$

For vapor flow, an ideal gas-specific heat ratio is most commonly used for sizing vapor flow. However, the ideal gas-specific heat ratio at the relieving temperature is recommended to be used for a system where the compressibility factor is greater than 0.8 and less than 1.1. Kim and others [*9*] presented a vapor-flow sizing method

TABLE 1. A SUMMARY OF EXAMPLE 1 CALCULATIONS			
	One-data-point method	Two-data-point method	Three-data-point method
v(ft^3/lb) at 114.7 psia	v_0=0.016069	v_0 = 0.016069	v_0 = 0.016069
v(ft^3/lb) at 64.7 psia	N/A	N/A	v_1 = 0.016071
v(ft^3/lb) at 14.7 psia	N/A	v_1 = 0.016074	v_2 = 0.016074
α value	15.08888	15.14525	1.13548
β value	0.00001	0.00001	0.000133
P_{ec} at 14.7 psia	0.0302	0.0303	0.0303
Mass flux, lb/s-ft^2	7,592	7,592	7,592

using a real-gas specific-heat ratio in Equation (7). This method provides more satisfactory results over a wide range of conditions than the conventional method with ideal-gas-specific-heat ratio. The more rigorous method uses the isentropic expansion coefficient in Equation (8).

Although the isentropic expansion coefficient is not constant during the vapor expansion, the isentropic expansion coefficient method does provide better mass flux predictions. Alternatively, an average isentropic coefficient value between the reservoir pressure and the pressure in the throat of the relief valve nozzle can be considered. The two parameters for vapor flow are α and ß, defined below:

$$\alpha = 1 \qquad \beta = \frac{1}{n}$$

$$n = k_{0*}$$

$$n = a + bY + cY^2 + dY^3 + eY^4 \qquad (7)$$

Where:

$$Y = Z_0 k_0 \left(\frac{2}{k_0 + 1}\right)^{\frac{k_0+1}{k_0-1}}$$

a: 4.8422E–5 b: 1.98366 c: 1.73684
d: 0.174274 e: 1.48802

$$n = -\frac{v_0}{P_0}\left(\frac{\partial P}{\partial V}\right)_{T0} k_0 \qquad (8)$$

For two-phase flow, the one-point omega parameter method is generally used. However, it is not accurate for multi-component systems having boiling-point range greater than 150°F and highly non-ideal conditions. The two parameters for two-phase flow are the following:

$$\alpha = \omega \qquad \beta = 1.000001 \qquad (9)$$

$$\omega = \frac{x_0 v_{g0}}{v_0} + \frac{C_0 T_0 P_0}{v_0}\left(\frac{v_{fg0}}{h_{fg0}}\right)^2 \qquad (10)$$

Mass flux with two data points

The two-data-point method significantly improves the mass-flux predictions for non-ideal systems. The first data point is in the larger reservoir. Generally, the second data point comes from the relief-valve outlet pressure for liquid flow, which is 50% of the first-data-point pressure for vapor flow, and 90% of the first-data-point pressure for two-phase flow.

For liquid flow, there is no difference between the one-data-point method and the two-data-point method because the change in specific volume is negligible. However, the two parameters for liquid flow are the following:

$$\alpha = (v_1/v_o - 1)/((P_0/P_1)^{\beta} - 1) \qquad \beta = 0.00001 \qquad (11)$$

For vapor flow, Kim and others [*9*] proposed Equation (12) for the two-data-point method. For highly non-ideal systems, the best second data point is at the nozzle exit of the relief valve. The two parameters for vapor flow are:

$$\alpha = 1 \qquad \beta = \left(\ln\frac{v_1}{v_0}\right)\left(\ln\frac{P_0}{P_1}\right)^{-1} \qquad (12)$$

For two-phase flow, the second data point at 90% of the reservoir pressure provides accurate mass-flux predictions in most cases. A lower second-data-point pressure generally gives conservative mass-flux predictions. In some instances, lower second-data-point pressure gives better results. Near the thermodynamic critical regions, the best second data point is at the nozzle exit of the relief valve. The two parameters for two-phase flow are as follows:

$$\alpha = (v_1/v_o - 1)/(P_0/P_1 - 1) \qquad \beta = 1.000001 \qquad (13)$$

Mass flux with three data points

Using only three data points, Equation (2) enables the designer to perform accurate mass-flux predictions without the numerous isentropic flash calculations. The first data point is in the larger reservoir. Generally, the third data point comes from the pressure safety valve (PSV) outlet pressure for liquid flow, and is 50% of the first data point pressure for vapor flow and two-phase flow. The second data point is at the middle pressure point. The two parameters that are applicable to all flows are the following:

$$\alpha = (v_2/v_o - 1)/[(P_0/P_2)^{\beta} - 1]$$
$$\beta - \ln[(v_2/v_0 - 1)((P_0/P_1)^{\beta} - 1)/(v_1/v_0 - 1) + 1]/\ln(P_0/P_2) = 0 \qquad (14)$$

Obtaining the ß value requires iterations. Equation (14) can be solved with a "goal seek" tool on a spreadsheet. The initial value of 2 for ß is recommended.

EXAMPLE CALCULATIONS

In order to illustrate the use of the universal mass-flux equation, we consider the following examples given in the API-520 Annexes B and C [*1*]. Ref. [*1*] includes a general flow equation for homogeneous fluids.

The general equation evaluates numerically for any fluid by direct summation over small pressure intervals using the Trapezoidal Rule. The results of the API calculations are based on the numerical integration using numerous isentropic flashes. It is generally understood that the numerical integration method provides the most accurate mass flux if the integration step size is small. The smaller increment results in less error.

Water example

The first example calculates the theoretical-nozzle mass flux for water. The stagnation pressure of the relief fluid entering the nozzle is 114.7 psia. The stagnation temperature is 80.3°F. The backpressure on the relief valve is atmospheric pressure. All physical properties used and the calculated results with the universal mass-flux equation are listed in Table 1. The API result for the mass flux is 7,592 lb/s-ft^2.

Superheated air example

The second example calculates the theoretical nozzle mass flux for superheated air. The stagnation pressure of the relief fluid entering the nozzle is 114.7 psia. The stagnation temperature is 80.3°F. The relief valve discharges to the atmosphere. All physical properties used and the calculated results with the universal mass-flux equation are listed in Table 2. The API results for the mass flux and critical pressure are 379.1 lb/s-ft^2 and 60.7 psia, respectively.

Two-phase fluid example

The third example calculates the theoretical nozzle mass flux for a fluid from a hydro-desulfurization vessel. The fluid contains a significant amount of hydrogen at a high pressure. The stagnation pressure of the relief fluid entering the nozzle is 2,168.5 psia. The stagnation temperature is 80.3°F. The backpressure on the relief valve is atmospheric pressure. All physical properties used and the calculated results with the universal mass-flux equation are listed in Table 3.

For this example, one-data-point calculations are not performed because the necessary information is not readily available. The API results for the mass flux and critical pressure are 4,830.8 lb/s-ft^2 and 1,214.4 psia, respectively.

Figure 2 shows that a more precise prediction of specific volume is obtained by the three-data-point method. As the pressure ratio is decreased, the prediction accuracy with the two data points decreases slightly. The less precise prediction of specific volume produces a slightly larger mass-flux result than the API one given in Table 3. However, the prediction up to the pressure ratio of 0.76 is very accurate (Figure 2).

In many two-phase cases, choking occurs at around 90% of the initial pressure. That is why the two-data-point method uses the fluid properties at P_0 and 90% P_0. In some instances, it is more desirable to use the second fluid property at a lower pressure than the 90% P_0 (indicated by the column titled "two-data-point method –1"). The results with a lower second-data-point pressure are better than the predictions with the ordinary two-data-point method (Table 3).

This lower second data point minimizes the error associated with extrapolation. Therefore, without any proven guideline for lower-accuracy options, a three-data-point method must be used to ensure the most appropriate relief-valve sizing.

Although the one-data-point method has provided satisfactory results over a wide range of conditions, higher-accuracy methods with more than one data point are often useful at high pressure or critical pressure regions.

TABLE 2. A SUMMARY OF EXAMPLE 2 CALCULATIONS

	One-data-point method	Two-data-point method	Three-data-point method
v(ft^3/lb) at 114.7 psia	v_0 = 1.741	v_0 = 1.741	v_0 = 1.741
v(ft^3/lb) at 85.7 psia	N/A	N/A	v_1 = 2.141
v(ft^3/lb) at 57.7 psia	N/A	v_1 = 2.835	v_2 = 2.835
α value	1	1	0.996973
β value	0.7143 (k_0*=1.4)	0.709662	0.711138
Choked pressure (P_{ec} = P), psia	60.59	60.42	60.47
Mass flux, lb/s-ft^2	378.3	379.1	378.9

TABLE 3. A SUMMARY OF EXAMPLE 3 CALCULATIONS

	Two-data -point method	Two-data -point method –1	Three-data-point method
v(ft^3/lb) at 2,168.5 psia	v_0 = 0.19305	v_0 = 0.19305	v_0 = 0.19305
v(ft^3/lb) at 1,908.3 psia	v_1 = 0.20964	N/A	N/A
v(ft^3/lb) at 1,648.1 psia	N/A	N/A	v_1 = 0.23364
v(ft^3/lb) at 1,040.9 psia	N/A	v_1 = 0.33784	v_2 = 0.33784
α value	0.630254	0.692345	0.570373
β value	1.000001	1.000001	1.143646
Choked pressure (P_{ec}=P), psia	1,183.91	1,210.89	1,227.08
Mass flux, lb/s-ft^2	4,961.1	4,841.3	4,851.8

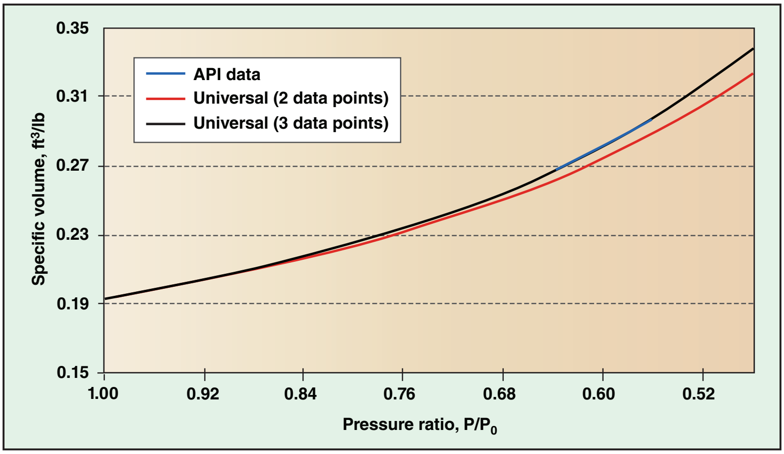


FIGURE 2. Specific volume predictions are very accurate across a range of pressure ratios

SIZING ACCURACY

The accuracy of a theoretical nozzle mass-flux prediction is entirely dependent upon the quality estimate of the specific volumes during an isentropic

NOMENCLATURE

- C liquid specific heat at constant pressure, Btu/lb-°F
- G theoretical mass flux, lb/s-ft^2
- h enthalpy, Btu/lb
- k gas or vapor specific heat ratio
- M gas or vapor molecular weight
- n isentropic expansion coefficient
- P absolute pressure, psia
- T absolute temperature, R
- v specific volume, ft^3/lb
- Z gas or vapor compressibility factor
- α, β, ω parameters for a pressure-specific volume correlation

Subscripts

- 0,1,2 physical property data states
- c choked (critical) conditions
- ec equivalent choked (critical) conditions
- f liquid
- fg difference between vapor and liquid properties
- g vapor
- * ideal conditions

expansion process. The universal mass-flux equation clearly illustrates why using good specific volume data is important for proper relief-valve sizing. One-data-point calculations involve assumptions that generally restrict the quality of the calculation results. However, the calculation results are still satisfactory and commonly used within the verified limits of applicability.

The calculations with more than one data point will definitely improve the mass-flux prediction. Therefore, the current trend of relief valve sizing is changing to use more than one data point. The one-data-point method is more likely to be inaccurate for handling fluids that depart significantly from ideality. As the number of data points increases, the mass-flux quality will increase accordingly.

The universal mass-flux equation can be used to check the specific volume estimates actually used in the sizing calculations. Therefore, it is necessary to compare the specific volume estimation at the nozzle exit pressure with the correct physical property data if only one or two data points are used in the sizing calculations. If they are significantly different, the calculations should be repeated with more data points or using the correct physical property as a second data point. As demonstrated in the example calculations, the universal mass-flux equation is a simple, flexible and powerful tool for sizing relief valves. ■

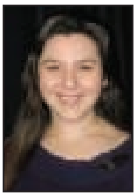
Edited by Scott Jenkins

References

1. American Petroleum Institute. "Sizing, Selection, and Installation of Pressure-relieving Devices in Refineries," API Standard 520, Part I — Sizing and Selection, December 2008.
2. Center for Chemical Process Safety (CCPS). "Guidelines for Pressure Relief and Effluent Handling Systems," AIChE, New York, 1998.
3. Leung, J. C., Easily Size Relief Devices and Piping for Two-Phase Flow, *Chem. Eng. Prog.*, pp. 28–50, December 1996.
4. Darby, R., Size Safety-Relief Valves for Any Conditions, *Chem. Eng.*, pp. 42–50, Sept. 2005.
5. Crowl, D. A. and Louvar, J. F., "Chemical Process Safety: Fundamentals with Applications," Prentice-Hall, Englewood Cliffs, NJ, 1990.
6. Diener, R., Schmidt, J., Sizing of Throttling Device for Gas/Liquid Two-Phase Flow, *Process Safety Progress*, 23 (4), pp. 335–344, 2004.
7. Simpson, L. L., "Navigating the Two-Phase Maze," in International Symposium on Runaway Reactions and Pressure Relief Design, G. A. Melhem and H. G. Fisher, eds., Design Institute for Emergency Relief Systems (DIERS), AIChE, meeting held in Boston, pp. 394–417, Aug. 2–4, 1995.
8. Leung, J.C., Grolmes M, A Generalized correlation for flashing choked flow of initially subcooled liquid, *AIChE J,* 34(4), April 1988.
9. Kim, J. S., Dunsheath, H.J., and Singh, N. R., "Proper Relief-valve Sizing Requires Equation Mastery," *Hydrocarbon Processing,* pp. 77–80, December 2011.

Authors

Jung Seob Kim is a senior process engineer at SK E&C USA Inc. (1401 Enclave Parkway Suite 100, Houston, TX 77077; Phone: 281-258-2619; Email: jkim3@sk.com) where he is responsible for designing petrochemical and petroleum refinery plants. He has more than 25 years of experience in different roles with the petrochemical process industry including with Bayer Technology Services, Samsung BP Chemicals and Samsung Engineering. He holds a B.S.Ch.E. from the University of Seoul, is a member of AIChE, and is a registered professional engineer in the State of Texas.



Heather Jean Dunsheath is a pressure safety specialist at Bayer Technology Services (8500 West Bay Road MS 52, Baytown, TX 77523; Phone: 281-383-6879; Email: heather.dunsheath@bayer.com) where she is responsible for designing emergency pressure relief systems and participates in process hazard analysis studies. She holds a B.S.Ch.E. from Rice University.

Navneet R. Singh is a senior process engineer at Bayer CropScience LP (8400 Hawthorne Road, Kansas City, MO 64120; Phone: 816-242-2738; email: navneet.singh@bayer.com) where he has experience with process design, process modeling, environmental and utility services, and emergency relief-system design. He holds M.S. and Ph.D. degrees from Purdue University, and B.S.Ch.E. from the Institute of Chemical Technology, Mumbai, is a senior member of AIChE and a professional engineer in West Virginia.

Environmental Permitting Barriers for Dryers and Kilns

Production of shale gas proppants is one area fueling installation of these units. Understand the equipment selection and regulatory hurdles

Thomas F. McGowan
TMTS Associates, Inc.

This article covers permitting and directly related design issues associated with thermal processes using drying and calcining for the production of both proppant sand and ceramic proppants (Figure 1) as an illustrative example (see sidebar, "What are proppants" on p. 41). The permitting issues vary significantly with air-quality "attainment area" status, but oxides of nitrogen (NOx), carbon monoxide and particulate matter are always the major issues. With proper design and operation, these emissions can be controlled at a reasonable cost.

Dryers and kilns

Dryers are required to dry and de-agglomerate sand for screen sizing, while high temperature kilns are required to calcine and harden the ceramic proppant product.

Sand drying is done in either a rotary dryer (Figure 2) or fluidized-bed dryers. A temperature of 250°F yields a product suitable for screening. It would be tempting to believe that such a low-temperature process will produce little NOx from the required burners, but while process gas and solid product are low in temperature, fuel economy dictates relatively low excess air in the burner system, which in turn results in higher flame temperatures and NOx concentrations.

Production of ceramic proppants takes much higher temperatures and is done in refractory lined kilns (Figure 3). These temperatures are in the range of that of cement manufacture, with rotary coolers (similar to those used in cement kilns (Figure 4) to cool the product. The rotary coolers also preheat combustion air to almost 2,000°F. Such high air-preheat temperatures reduce fuel use, but also exponentially increase NOx concentrations.

Emissions and regulations

In brief, the regulatory issues are NOx, CO and particulate emissions, in decreasing order of importance. These are the main concerns when natural gas and propane are the predominant fuels, but if fuel oil is used, SO_2 may also come into play.

A big issue is location and siting of a facility. Permitting and operating are easier in air quality "attainment areas", as designated by national ambient air-quality standards (NAAQS). If the plant must be located in a "non-attainment area" for ozone (NOx is a precursor for ozone), additional controls and cost may result. If this is an expansion of an existing facility, the existing Title V permit will have to be updated. In some cases, taking a voluntary annual operating-hour limit to cap the tons per year of a particular emission may be instrumental in keeping capital and operating costs in line. In short, given higher constraints, it is unlikely that a facility of any size would choose to site itself in an ozone non-attainment area.

In addition, the magnitude of the emissions may trigger New Source Review (NSR) permitting, an expensive and lengthy exercise, which may require post-combustion controls or acquire internal or external emission offsets in order to permit the modification. Alternately, it may be wise to cut capacity during design to a level that will not trigger NSR for a given location.

Carbo Ceramics

FIGURE 1. A handful of ceramic proppants is shown here

The U.S. Environmental Protection Agency's (EPA) AP-42 Compilation of Air Pollutant Emission Factors is a frequently used resource in producing the permit application. It is available online, and one can look up emissions for various applications by industry and by fuel. A link to AP-42 is contained in Ref. 2.

For hydraulic fracturing (frac) sand dryers and ceramic proppant producers, the minerals industries subsection (AP-42 Chapter 11) can prove useful in writing permit applications. While AP-42 is updated from time to time, advances in low-NOx burners may not have been captured in the emissions factors, and judiciously applied (and proven by stack test) vendor data are also a good resource. Similarly, AP-42 may not have a process similar enough to the high-temperature kilns for ceramic proppants, and input from similar process stack tests may be of importance.

Best practices

The author has worked on reducing emissions from both rotary dryers and kilns used for proppant manufacture, on limiting NOx from firing of fluidized-bed dryers, and controlling volatile organic compound (VOC) emis-

TMTS Associates

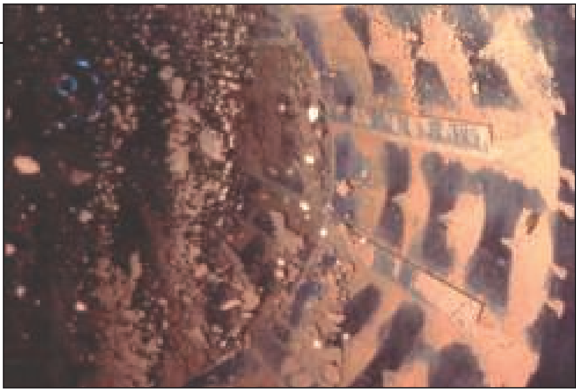


FIGURE 2. This photo shows how flights lift and drop sand through the hot gas stream in a rotary dryer

Carbo Ceramics

FIGURE 3. A view of a refractory lined kiln for producing proppants is shown in this photo

WHAT ARE PROPPANTS?

The "gold rush" is on — drilling for shale gas across multiple U.S. states — and this new source of natural gas is shaking up the fuel market and cutting fuel costs for a wide range of industries. A critical ingredient that has made this possible — proppants — is used to prop open the fissures created by hydraulic fracturing (fracing).

Well-bore proppants are made from specially sized and chosen sand, or from ceramic beads (Figure 1) made in a high-temperature process from a mixture of kaolin and other minerals. The production company's (companies that drill gas and oil wells) geologists and drilling engineers pick the right size range and crush strength required to keep the pores in the geological structure open after the geological strata has been fractured by high-pressure fracing fluids. The proppant works much like the timber shoring used in old shaft mines to support the roof, but in this case, the shoring is being done on a micro scale.

Proppant crush strengths are generally 5,000 to 9,000 psi, and they are made in sizes ranging from 20 to 80 mesh. Tighter ranges (for example, 20–40 mesh) are used for specific applications. Mesh sizes refer to screen size used in sizing them, with 80 mesh being 0.0071 in. (180 microns) and 20 mesh being 0.0331 in. (840 microns) on the U.S. Standard screen scale.

There is a hierarchy for proppants, with the ceramic type having the highest conductivity, ultimate gas recovery, and gas production rates. This is due to superior sphericity, high crush strengths and lower settling rates as compared to uncoated "frac" sand. Next come resin-coated sand, then uncoated frac sand. The uncoated frac sand producer's selling point is lower initial cost and potential for local supply. More information on the tradeoffs of the competing types can be found in the production-related trade journals [*1*]. ❑

sions from a proppant resin-coating operation. Major tools involved in fixing the problem follow for specific applications. A general one to add here is stack height. It is not unusual for regulators to require a dispersion model, and short stacks become a great disadvantage when dispersion models are applied. We suggest that 75 ft (23 m) should be considered an absolute-minimum stack height if there is a chance that such modeling might be required in the future.

Particulate matter control

To address the easiest issue first, baghouses are used for particulate control. Limits vary, with a recent project being at 0.025 g/dscf (grams per dry standard cubic feet; or 56 mg/m^3). This is not hard to achieve with a good baghouse (Figure 5) and good bag filters for both dryer and kiln applications. The limit is for the "front half catch," which encompasses hard particulate matter only, and excludes any "back half catch" limit that might be imposed. Keep in mind that other sources, such as conveyor transfer points, may get added into the total particulate matter for the site.

NOx control

For new rotary dryers, the simple choice is to use a "closed-in burner" that is of a low-NOx design. For many plants, this will reduce the NOx emissions to under 250 ton/yr, a frequent site-wide limit for ozone attainment areas. Older design "open burners," which get about 70% of their combustion air from a gap between the burner face and the dryer drum, have significantly higher NOx and CO emissions, and while being cheaper to buy, are not the right choice when seeking low emissions.

Fluidized-bed dryers use a variety of pressurized forced-draft burners to supply hot gas to the fluidizing grid. The author specified a new-generation line burner for one fluidized-bed application, with two vendors offering a guarantee of <30 ppm NOx at 3% O_2, much lower than standard line burners. This system had "smart valves" and upgraded controls to make this possible.

For dryers where the vendor has placed similar burners firing at similar excess air levels, NOx is expected to be in the range guaranteed by the burner vendor. One should be careful about the vendor's NOx oxygen basis, which is typically in the form of ppmdv (parts per million dry basis) at 3% oxygen, when using it to compare to regulatory limits, which may require conversion to a different oxygen basis. They may also require translation into tons-per-year mass emissions; obviously, the stack-gas flow must be known to do this conversion.

For high-temperature kilns, the author's employer has used some of its tried-and-true combustion modification techniques, those being low oxygen firing coupled with a limited amount of water injection into the combustion zone. This has resulted in over 50% reduction in tons per year NOx mass emissions, and seven-figure annual fuel savings. There are design issues associated with these changes — such as draft control (as flow through the system drops, seals may be subjected to chimney-effect positive pressure) and refractory temperature limits — that must be addressed as part of the change in process.

Can you buy a low NOx burner for a high-temperature kiln with high-temperature air preheat? Kiln burner companies like to claim their burners are low NOx. However, guarantees are thin for the kiln-style preheated air burners, and with about 90% of the air coming through the rotary product cooler/air preheater and only 10% through the burner. Equilibrium effects may overshadow any abilities of a burner to control NOx due to the ultra-high combustion temperatures and long residence time in the hot zone of the kiln.

Can end-of-pipe controls be added to reduce NOx? The answer is that SCR (selective catalytic reduction) systems have been used for other applications, but to the author's knowledge, these have not been applied to proppant manufacture in the U.S. They would add significant capital and operating costs, may require preheating the gas after it leaves the baghouse, and there is always a risk that catalysts may fail due to small amounts of poisoning or fouling agents in the particular process feedstock. The SCR solution has not-so-green side effects, such as adding to fuel use and emissions for reheat, adding to power requirements for higher pressure drop that result in utility based emissions, and manufacture and transport of ammonia and similar reagents that cause safety concerns.

Are there other alternatives? While to the author's knowledge, they have not been applied to ceramic proppant production, some work has been done on staged fuel rich/lean combustion in cement kilns (rich firing at the burner, with a zero oxygen in the combustion products, then more air added further down the kiln to complete combustion, but at a lower temperature, with lower expected NOx concentrations). Cement kiln results claim NOx reductions of 11 to 55% [*3*]. Due to lack of proppant-application data, this would have to be considered an experimental approach.

SNCR (selective non-catalytic reduction) could theoretically be applied to proppant kilns, with injection of ammonia or other reagents via mid-kiln ports. To the author's knowledge, this has not been done in any proppant kiln, and would also be considered experimental.

With either the rich/lean or SNCR approaches, mixing, and finding the optimum location in the kiln temperature and reaction chemistry to input air or reagents are significant challenges. Both complicate operation of the kiln process and will make it more difficult to keep the process stable.

Carbo Ceramics

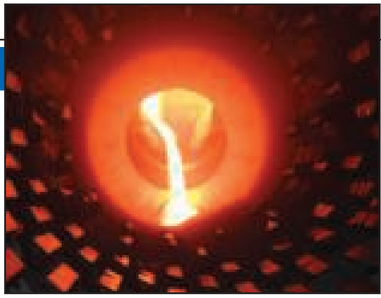


FIGURE 4. The incadescent ceramic-proppant stream is seen here entering a rotary cooler downstream of the kiln

TMTS Associates

FIGURE 5. Shown here is a filter bag with cages and blow pipes in the background

As with particulate matter, keep in mind that other sources, such as onsite boilers, backup or prime generators, and upstream fired thermal equipment will add to the total NOx emissions for the site.

Even though NOx is almost entirely NO for the above applications, on a mass basis, NO_2 is used by EPA, with a molecular weight of 46 lb/mol versus 30 lb/mol for NO.

CO control

CO and NOx are linked through the combustion process. For example, if low O_2 firing is used to reduce NOx by operating close to the stoichiometric ratio (zero percent excess air), cutting O_2 too far will result in a CO spike. A frequently used regulatory benchmark-limit is 250 ton/yr for CO, for a site total. CO varies with fuel, with propane yielding about 25% higher CO on some burners than on natural gas, and with CO levels higher yet for No. 2 fuel oil. Combustion is not all science, and some of the art includes the mating of the burner and the application, and control of air that does not come through the combustion air train. Good seals and control of dryer or kiln draft are critical in keeping the combustion environment in a stable and low-emissions process operating envelope.

Burner vendors should provide a CO guarantee along with NOx control guarantees.

A wild card for CO (and VOCs) is the existence of kerogens in the feedstock. This is a site-specific issue, as kerogens are naturally occurring organic materials (for instance, peat), which when heated, devolatilize and give off VOCs and may also contribute to CO emissions.

Resin-coated sand

A potential regulatory issue of smaller magnitude is VOC emissions from resin coating of sand. RTOs (regenerative thermal oxidizers) are the usual fix, with typical permitting goals of reaching >95% VOC destruction.

Final remarks

The shale gas market is consuming more and more proppants to optimize gas recovery. Manufacturers that want to add proppant capacity must make significant decisions early as they work on siting and permitting the facilities to allow fast implementation. Choosing the right combustion and air-pollution control equipment is critical to minimizing NOx, CO and particulate emissions, limiting capital and operating costs, and maximizing the potential proppant production at a given site. ■

Edited by Gerald Ondrey

References

1. Percival, Pamela, Proppant demand rising, technology improving, *Basin Oil and Gas*, January 2010, Issue No. 25, www.fwbog.com/index.php?page=article&article=196
2. U.S. EPA AP-42 Compilation of Air Pollutant Emission Factors, www.epa.gov/ttn/chief/ap42/ch01
3. Hansen, Eric R., Staged Combustion for NOx Reduction Using High Pressure Air Injection, IEEE, 2002, www.cadencerecycling.com/resources/ieee2002.pdf

Author

Thomas F. McGowan is president and founder of TMTS Associates Inc. (399 Pavillion Street, Atlanta, GA 30315; Phone: 404-627-4722; Email: tfmcgowan@mindspring.com; Website: www.tmtsassociates.com), a firm that specializes in thermal systems and air-pollution control. Prior to starting the firm in 1998, he was previously employed by RMT/Four Nines, Envirite, the Georgia Tech Research Institute, and Particulate Solid Research, Inc. McGowan has 40 years of experience in combustion, air pollution control, and solids handling, and received the *Chemical Engineering* Magazine 2010 Award for Personal Achievement. He holds an M.S.Ch.E. from Manhattan College in New York City, and an M.S. degree in industrial management from Georgia Tech.

Sizing, Specifying and Selecting Centrifugal Pumps

Follow these tips to determine preliminary pump sizing, to support cost-estimation efforts

Asif Raza
Zeton Inc.

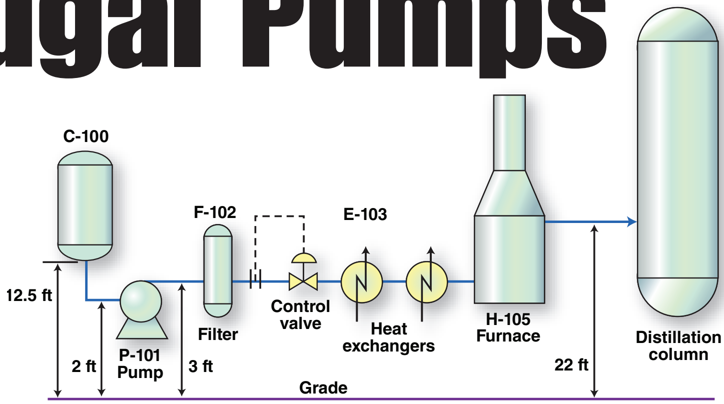


FIGURE 1. Refer to this pump-system sketch for the pump-design calculations discussed here. Note, a distance of 2 ft between the pump-inlet piping and grade and 3-ft distance between pump-discharge piping and grade is assumed during initial sizing. These values should be confirmed once pump selection is done

Determining the proper preliminary size for centrifugal pumps during the initial stages of any pump-specification exercise requires numerous calculations and assumptions. This article reviews the steps needed to size centrifugal pumps during the early stages of a project, to support initial cost-estimation efforts. Such early pump-sizing efforts are important steps toward final pump selection and detailed engineering.

Sizing centrifugal pumps

Normal flowrate and rated flowrate. To define the normal and rated flowrates, refer to the heat and mass balance of your project. Normal flowrate is the flow at 100% capacity. Rated flowrate is the design margin that is added to the normal flowrate (typically on the order of 10–30%), to accommodate potential short-term excursions in flowrate during operation. Rated flowrate is usually defined by the user. If it is not defined, consider 10% for normal-service pumps, and 20–30% for critical-service pumps, such as distillation column reflux pumps, reactor feed and furnace-feed pumps and other feed pumps that play a critical role in the overall process.

Pressure-drop calculations. The intent of these calculations is to determine suction pressure and rated differential pressure. Please refer to sample calculation #1 (discussed below) and Figure 1 for performing pump-sizing calculations, which include calculation of suction pressure and rated differential pressure.

Net pressure suction head (NPSH) calculations. During the early stages of the project, the plant layout is not yet firm. Hence, NPSH available for the pump(s) cannot yet be calculated with confidence. However, it is okay to carry out preliminary NPSH calculations using information from the preliminary layout. Note that NPSH values can be increased by later modifications to the layout. NPSH plays a very important role during pump selection, and could significantly impact the cost of the pump if a lower-NPSH (required) pump is specified, since pumps with a lower NPSH requirement tends to be more expensive. The goal is to calculate a preliminary NPSH value and provide it to the pump vendors to get initial feedback. This allows both parties to determine whether a pump with the specified NPSH can be achieved or not, can be achieved with some modification to the plant layout, or can be achieved by selecting a pump with lower NPSH requirements. Based on the vendor's feedback, modify your layout to have a design margin between the available and required NPSH. A design margin of 3–4 ft is widely accepted, per industry standards. See sample calculation #2 for calculating NPSH (available).

Horsepower and efficiency. In the early stages of the project, you will have to provide preliminary horsepower to the electrical engineer for load calculations. From the rated differential pressure, calculate the rated horsepower. Since the pump has not yet been selected, you can assume a pump efficiency between 50 and 60%. Make a judgment call — 50% is typically a sufficient value for calculating horsepower during the initial stages of a project.

Shutoff pressure. Shutoff pressure is required in early stages of the project to determine the flange rating for the discharge piping of the pump. There are several ways to calculate shutoff pressure. A more conservative method uses the following formula:

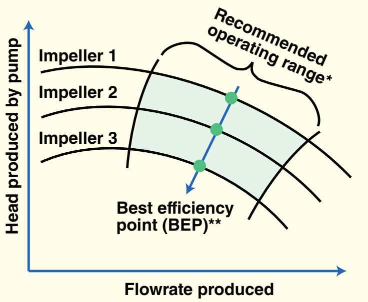
Differential pressure × 1.25 + maximum suction pressure

Maximum suction pressure is calculated by:

Pressure safety valve (*PSV*) set pressure × 10 – 21% accumulation + static head based on high liquid level

If a user does not have information such as the PSV set pressure in the early stages of the project, a simple approach for calculating shutoff head is to use this formula:

Rated differential head × 1.5



* The recommended operating range is between 70–120% of the BEP flowrate

* * BEP is a point on the curve, is specific to each pump, and is provided by the pump manufacturer

FIGURE 2. This pump-performance curve shows the best efficiency point (BEP) and the recommended operating range, which are helpful during pump selection. Note the shaded region represents the operating range for different impeller sizes

TABLE 1. PUMP-SIZING SPREADSHEET FOR CALCULATING SUCTION PRESSURE AND RATED DIFFERENTIAL PRESSURE (CALCULATION #1)

	Rated flow condition	Normal flow condition
Suction pressure		
Source pressure, psig	30	30
Static head = 10.5 ft (ft x specific gravity/2.31), psi	3.2	3.2
Suction line loss, psi	0.3	0.3
Pump suction pressure, psig	(30+3.2) -0.3 = 32.9	(30+3.2) -0.3 = 32.9
Discharge pressure		
Delivery pressure, psig	100	100
Static head = 19 ft (ft x specific gravity/2.31), psi	5.8	5.8
Line loss, psig	33	23
Control-valve pressure drop, psid	38	83.5
Filter pressure drop, psid	14.4	10
Heat exchanger 1 pressure drop, psid	14.4	10
Heat exchanger 2 pressure drop, psid	14.4	10
Furnace pressure drop, psid	72	50
Orifice flowmeter pressure drop, psid	2.88	2
Contingency, psig	10	10
Differential pressure, psig		
Discharge pressure, psig	=100+5.8+33+14.4+14.4+14.4+72+2.88+38+10 =305	=100+5.8+23+10+10+10+50+2+83.5+10=305
Minus suction pressure, psig	32.9	32.9
Total pump differential pressure, psig	272	272
Pump head (psi x 2.31/specific gravity)	900	900
Hydraulic power = gal/min x pump head (ft) x specific gravity/3,960, hP	382	318
Efficiency at 3,600 rpm, %	60	60
Rated power = Hydraulic power/efficiency, hp	637	530

Specifying centrifugal pumps

The following steps must be carried out during the specification of centrifugal pumps:

Gather basic process data. Fill out the pump data sheet with the following basic information: Suction pressure, normal and rated discharge pressures, normal flowrate and rated flowrate, fluid properties, such as density, viscosity and vapor pressure at operating temperature.

Determine a preliminary value for NPSH. Please refer to the NPSH calculations presented below (sample calculation #2).

Specify desired materials of construction. This should come from the end user or from a metallurgist who is involved in the project and is responsible for specifying the appropriate metallurgy of the equipment.

Specify sealless versus mechanical seals. Magnetic-drive sealless pumps are desirable for many applications since they eliminate the need for mechanical seals, and thus eliminate the inherent risk of leakage and maintenance associated with such seals. But sealless pumps also have drawbacks, such as an inability to handle larger particles in the process fluids. And in some applications, relatively high differential pressure requires high torque, which may be beyond the capabilities of the sealless pump.

Rely on the end-user's experience regarding whether to use a sealed or sealless design pump. Consider sealless pumps for liquids that are flammable, toxic and corrosive. For instance, many facilities use traditional sealed pumps for pumping water, and sealless pumps for pumping acids and alkalis and other corrosive liquids.

Work closely with your vendor and seek guidance based on previous experience in applications with similar service. If a sealless pump is not available, consider using a double mechanical seal to minimize the risk of leakage. Rely on the vendor's experience, as well, in selecting the most appropriate mechanical seal for your service. Provide vendors with as much process data as you have, to ensure proper seal selection for your service.

Classify non-ANSI, sub-ANSI and ANSI–API pumps. Ultimately, the selection of specific centrifugal pumps must be based on the end user's requirements, process conditions, and the cost of the equipment. In general, the cost increases in this order: Non-ANSI, sub-ANSI, ANSI and API, while non-ANSI pumps have the lowest cost. A non-ANSI pump usually finds its application in small sizes handling less critical service, such as water that is being pumped at relatively low pressure and low temperature. An ANSI pump is usually used in applications requiring relatively larger sizes (for instance, more than 10 hP) in chemical or hydrocarbon service.

However, some ANSI pumps may be limited to a maximum casing pressure. For higher-casing pressures, the user may have no choice but to consider a custom-made pump or an API pump. API pumps tend to be considerably more expensive than ANSI pumps, as they are typically used in hydrocarbon

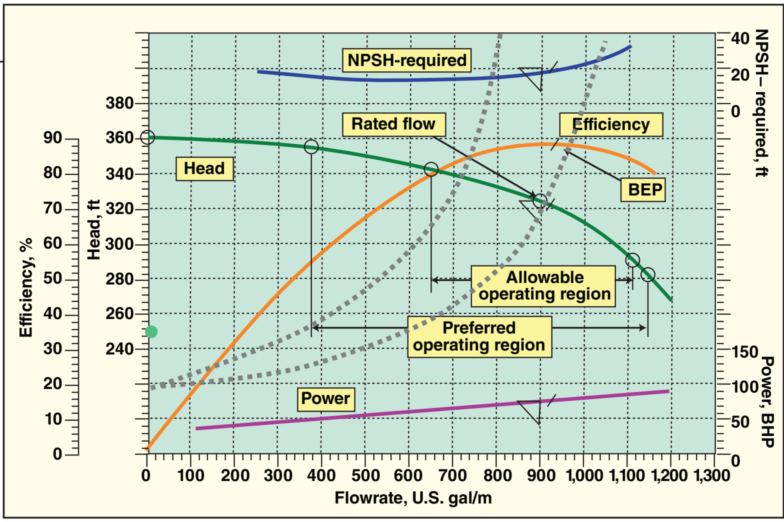


FIGURE 3. This figure shows a relationship between flowrate and head, power, efficiency and NPSH. Note the NPSH curve is bowl-shaped. NPSH requirements increase with flow. Make sure you analyze this value carefully and select a NPSH (required) value that corresponds to the rated flowrate

service involving high temperatures and very high pressures. Such pumps are widely used in refinery service.

Specify design pressure and temperature. Specifying design pressure and temperature based on the design conditions of the pump suction vessel may seem to be the easiest approach. But check for any possible upset conditions that might warrant an increase in design pressure and temperature, such as a new process stream entering the pump suction in a different process operating mode.

Specify the motor requirements. The required power supply, whether it is 460 V at 60 Hz, or 230 V at 50 Hz, must be supplied by the end user. Lastly you have to specify the hazardous area classifications and temperature rating of the motor. Check with your electrical engineers to identify the required hazardous area classification. Motor temperature rating should also come from the end user. This is based on the lowest autoignition temperature of the components involved in the process. Keep in mind, most of the time, a motor rating up to T3A is available at no added cost, but the cost increases substantially if a motor with a rating of T4 or higher is specified.

Next, you need to specify whether you want a fixed-speed motor or a variable-speed drive motor. If you are controlling the pump flow with a speed controller, then you must select an inverted-duty, variable-speed motor. However, note that if there is a control valve on the pump discharge, then you must use a fixed-drive motor.

Sample calculations

Consider the pump system sketch shown in Figure 1. A fluid with a vapor pressure of 45.9 psia at operating temperature of 430°F with a viscosity of 0.5 cP is pumped at normal flow of 2,000 gal/min. The specific gravity is 0.7 and the delivery pressure is 100 psig. The operating pressure of column C-100 is 30 psig. The atmospheric pressure at site is 14.5 psia. Assume a rated flowrate of 2,400 gal/min (1.2 times the normal flowrate).

Note that two sets of calculations are done for calculating horsepower — one for normal flowrate and other for rated flowrate. Refer to Figure 1 for calculating static head. Pressure drop across filters, heat exchangers, orifice meters and furnaces are taken from actual equipment vendor quotes. These quotes may be available from different disciplines, such as mechanical and instrumentation departments.

If vendor quotes are not available during preliminary pump sizing, then assumptions must be made based on interactions with other disciplines. For instance, it is okay to assume a pressure drop of 10 psid across heat exchangers or a pressure drop of 5–10 psid across a filter. Pressure drop across a vessel filled with catalyst should be calculated using the Ergun equation. These pressure-drop values are finalized when equipment design is finalized and are used for final pump sizing, during the detailed engineering phase, to check the rated differential pressure and rated brake horsepower. It is helpful to perform these calculations using an Excel spreadsheet.

The pump-sizing calculations also provide pressure-drop data across the control valve, under normal- and rated-flow circumstances. Specify control-valve pressure drop at the rated flow, following the widely accepted rule of thumb — that is, pressure drop is 25% of the dynamic head loss at rated flow. In this case, dynamic head loss at the rated flow is 151 psig (the sum of pressure drop across filters, heat exchangers, furnaces, orifices and line losses. Hence the differential pressure across the control valve in this scenario at rated flow is 38 psig).

Note: If the calculated pressure drop across the control valve is less than 10 psig, use a minimum value of 10 psig for the control valve at rated flowrate. Now adjust the pressure drop across the control valve at normal flow and try to match the discharge pressure until it is equal at normal and rated flow. Pressure drop is directly proportional to the square of the flow, hence pressure drop across rated flow is calculated using the following formula (Note that the rated flow is 1.2 times the normal flow):

Filter pressure drop at normal flow = 10 psig

Filter pressure drop at rated flow = $10 \times (1.2 \times 1.2) = 14.4$ psig

In reality, the discharge pressure at normal flow and rated flow may not be the same, but the two values will be very close. A pump is designed to operate at rated flow conditions. However, a pump operates at normal flow most of the time during normal operation.

Normal operation

During normal operation, because the flow is lower than the rated flow, the pump will try to develop more head. During this scenario, the control valve will start closing and will consume more pressure drop. This will have the effect of moving the pump back onto the pump curve.

Here, you will notice that pressure difference in rated flow is 38 psig (specified by the designer) and is 83.5 psig in normal flow. The difference between these two values is the excess dynamic head between normal flowrate and rated flowrate. The relationship between the pump's head-capacity curve and pipe-system relationship resistance is shown in Figure 4.

Pressure drop across the control valve should not be included as a part of the dynamic head loss. The gap between the head-capacity curve and the system-resistance curve is available for throttling (control-valve pressure drop). Control valve pressure drop at normal flow is higher than the pressure drop at rated flow. While pipe dynamic head loss increases at higher flowrates (rated flow), control-valve pressure drop decreases. At higher flowrates, the control valve has to open more and pass larger flow with less resistance.

Designers should appreciate the importance of specifying the correct pressure drop for the control valve at different flow conditions, to ensure a rugged system design. If a system is poorly defined, the pump will never be able to control the flow and it will never provide proper flow at the required head. The efficiency will be low and the pump will consume more power.

It is also advisable to install a globe valve at the pump discharge, to allow for throttling the flow and adjusting the flow and discharge pressure. However, please keep in mind that the installation of a globe valve will incur a constant pressure drop, which must be accounted for during head-loss calculations.

Ultimately, the calculated control-valve pressure drop at normal and rated flows will be given to the instrument engineer who is responsible for specifying and sizing the control valves for your project.

Sample calculation #1. Table 1 shows the results of a pump-sizing exercise, in which suction pressure and rated differential pressure were calculated.

Sample calculation #2. Static pressure available at the pump suction inlet = (Operating pressure of the vessel + static head) – suction-piping head loss at rated flow.

NPSH (available) = Static pressure at the pump suction inlet – vapor pressure at the operating temperature. The results of these sample calculations are shown in Table 2.

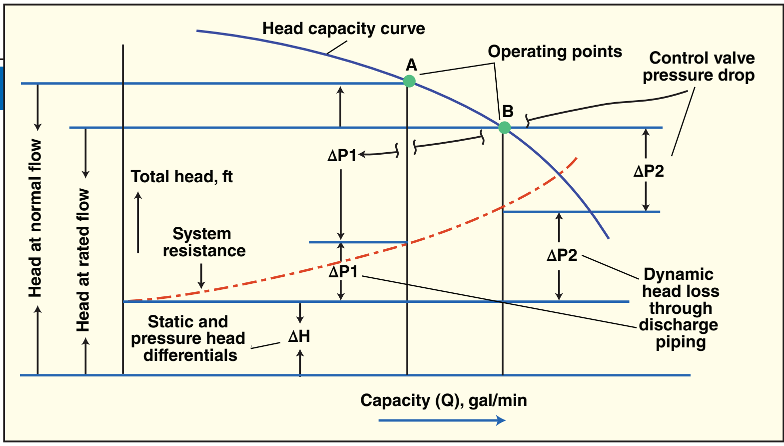


FIGURE 4. This figure shows the relationship between a pump's head-capacity curve and pipe system resistance (dynamic head loss). It also shows pressure drop across a control valve at normal and rated flowrate. Note: Pressure drop across the control valve at rated flow is less than the pressure drop at normal flow

Pump selection

During this stage of the project, you should be getting quotes back from the vendor, based on the pump specifications you have provided. While various quotes will vary in their dollar value, keep in mind that a more-expensive pump does not necessarily mean that it is the best pump for the job, and the least-expensive pump is not worth further consideration. To assess competing quotes fairly, develop a spreadsheet to gather the following selection criteria. Assign points to each item that meets your specifications.

NPSH. Check for NPSH (required) from the pump data sheet provided by the vendor. How close it is to your estimated value of NPSH (available)? Ask yourself — Can you make this pump work by increasing NPSH (available)? It cannot be stressed enough that NPSH is a key parameter during pump selection, and insufficient NPSH often results in pump cavitation.

Cavitation occurs when vapor bubbles that have formed in areas of low static pressure move along the impeller vanes into high-pressure areas, where they rapidly collapse. The forces produced by these bubbles as they implode erode the impeller vane, resulting in progressive pitting to the impellers. As a rule of thumb, an acceptable margin between NPSH (available) and NPSH (required) is required to ensure pump reliability. A minimum margin of 3–4 ft is a widely practiced rule of thumb. Since the NPSH requirement increases with increasing flow, it is important to consider the maximum expected flow when specifying an acceptable NPSH margin.

Rated flow and differential pressure. Analyze all quotes to see whether they meet your specified value of rated flow and differential pressure.

Material of construction. Does this meet your specified material of construction?

Analyzing pump curve and efficiency. Pump efficiency is a very important value to be considered. Some vendors may quote a bigger pump than what is required. In such a case, the pump efficiency will be reduced. Designers should note that a pump with even 10% higher efficiency will save thousands of dollars in power costs over the service life of the pump.

It is good practice to examine several performance charts at different speeds to see if one model satisfies the requirements more efficiently than another. Whenever possible, the lowest pump speed should be selected, as this will save wear and tear on the rotating parts. Efficiency can be found on the pump curve provided by the pump vendor. Refer to Figure 3, which shows the relationship between efficiency and flowrate. This figure also shows the relationship between volumetric flowrate, head, NPSH and brake horsepower.

Every pump has a best efficiency point (BEP), which is the flow/head combination that corresponds to the highest efficiency. The preferred operating region is between 70 and 120% of the BEP flowrate value [*1*], although most users require the rated flow to fall between 80% and 110% of BEP. The allowable operating region varies from pump to pump, and is defined as the flow range within which vibrations do not exceed the limits established by the American Petroleum Institute (API) [*1*].

Refer to Figure 2, for the recom-

TABLE 2. NPSH CALCULATIONS (CALCULATION #2)	
Atmospheric pressure, psia	14.5
Specific gravity (SG), dimensionless	0.7
Original pressure (vessel pressure), psig	30
Static head = 10.5 ft (Note 1)	(10.5/2.31) x 0.7 = 3.18 psig
Suction line loss, psig	0.3
Suction pressure at pump inlet flange, psia	=30 + 3.18 – (0.3) = 32.88 + 14.5 = 47.38 psia
Vapor pressure, psia	45.9
Net pressure suction head (NPSH) = Suction pressure – vapor pressure, psia	47.38 – 45.9 = 1.48 psia
NPSH available, ft	= 1.48 x 2.31/0.7 = 4.89

Note 1: Static head is measured from the low liquid level in the vessel to the center line of the pump-suction flange, or from the vessel bottom nozzle to the center line of the pump-suction flange. The latter is more conservative approach.

mended operating range. The shaded region represents the operating range, that is discussed in the above paragraph. Note in this figure, there are three curves for three different impeller sizes provided by the pump vendor. While selecting an impeller, it is good practice to select a pump with an impeller that can be increased in size, as this will allow for future increases in head and capacity.

Mechanical seal arrangements. When evaluating competing vendor quotes, be sure you are comparing "apples to apples." For instance, some vendors may have quoted a double mechanical seal, while your requirement was for a single seal. If this happens, ask the vendor to revise the quote.

Motors. Check for the motor sizing, and whether it has been sized for full run-out case. Full run-out means that the motor should be sized for the maximum flowrate the pump can deliver. The stated motor temperature rating and specified electrical area classification must meet your requirements.

Physical size of the pump. Check for the dimension of the pump from the quotes received. If space is tight, you may have to consider an inline pump, or a high-speed, single-stage pump over a multistage pump.

Design conditions. Check for design temperature and pressure from the vendor quotes and make sure that they meet your requirements.

Design codes. Does the quoted pump meet your specified design codes, such as API, ANSI and so on.

Warranty. When evaluating competing pump options, check for the manufacturer's performance warranties and for the availability of onsite startup assistance from the vendor, if specified in the Request for Quotation (RFQ).

Scope of supply for auxiliary equipment. Make sure the vendor's quote includes the supply of all the accessories required, such as lubrication-oil coolers, interconnecting piping between the coolers, instruments, such as flow switches on the cooling water lines and so on. Be sure to compare all the quotes on the same basis.

Price. Before selecting a particular pump, make sure that you are comparing "apples to apples," as different vendors may have quoted different pump options in different styles, with different seal arrangements, using different assumptions and so on.

Final thoughts

Close coordination with the pump vendor and developing a solid understanding of the process requirements are essential steps during pump design and selection. By understanding the concepts of rated flow, head, suction pressure and NPSH, and by understanding pump curves, you will be on the right track to design and select the most appropriate pump that meets all of the process requirements. ■

Edited by Suzanne Shelley

Reference

1. American Petroleum Inst. (API), "Centrifugal Pumps for Petroleum, Petrochemicals and Natural Gas Industries," 10th Ed., API Standards 610 (ISO 13709), Washington, D.C.

Author

Asif Raza is a lead process engineer at Zeton Inc. (740 Oval Court, Burlington, ON L7L 6A9, Canada; Phone: 905-632-3123; Email: asifraza_us@yahoo.com). His work involves the design and manufacture of pilot and demonstration units for research and development, in the areas of petroleum refining, petrochemicals, gasification and unconventional sources of energy, such as biomass, gas-to-liquids and coal-to-liquids. He has more than 15 years of experience in process design. His areas of interest include major equipment sizing and selection, P&ID development, selection of control logics and process simulation. Before joining Zeton, Raza worked as a lead design engineer with engineering, procurement and construction (EPC) companies, including Bantrel Inc. and SNC Lavalin Engineers and Constructors. He holds a B.Tech degree in chemical engineering from Amravati University (India). Raza is a registered professional engineer in the province of Ontario, and is a member of Ontario Society of Professional Engineers.

Accelerating Process and Product Development

Wiroon Tanthapanichakoon
SCG Chemicals Co.

These simple strategies can be used to speed up and increase the success rates of R&D projects

Research and development (R&D) projects usually require significant time, effort and manpower to become successful. Despite the significant resources spent on R&D projects, only 5–10% of the projects are statistically believed to be successfully commercialized, in terms of both timing and technological advances. Many projects fail because they cannot achieve the desired results on timing of commercialization and licensing.

This article is focused on providing systematic strategies to speed up both technical and non-technical aspects of R&D projects — especially new process development. It addresses certain aspects that have not been mentioned in previous technical references [*1–5*], such as basing R&D project management on manpower resource characteristics. It also presents strategies to speed up process development projects visually in a diagram (Figure 1) that is easy to follow and use.

OVERVIEW

Types of R&D projects

Research and Development projects can generally be classified into the four types listed below [*1*]:

- Basic research
- New application research
- New product development — In this article, new products are limited to those that are an intrinsic part of new process development, such as new catalysts and solvents
- New process development — As mentioned above, this can sometimes incorporate new products, such as catalysts and solvents. New process development is the focus of this article

Basic research and new-application R&D generally require less time and manpower, and involve a smaller group of people than do the development of new products and processes. This is because the goal of basic research is to develop fundamental knowledge that might be applicable for further development and commercialization in the future, and new application research focuses only on finding and developing new applications for existing products and processes, thus allowing much of the existing knowledge on existing products and processes to be utilized.

The most time-consuming part of R&D is often new process and product development on pilot and commercial scales. Accelerating new process and product development gives earlier and higher overall project-life benefits (Figure 2).

New process development often involves development of new products such as new catalysts, solvents and chemicals to be used in the new process. Thus, we define the scope of this article to also include development of new products that are an intrinsic part of the new process development, though not final products per se.

For example, a new butadiene extractive distillation process development requires the development of a new butadiene extraction solvent, but the solvent is not a final product of this process. Later in the article, we will refer to our new products as new catalysts and solvents (C&S) to avoid confusion.

Typical development steps

New product and new process development typically include the following steps toward commercialization. Figure 1 shows a flow chart visualizing all steps and strategies to speed up development projects during each step.

1. Laboratory-scale new product (C&S) development and validation. Consider using special tools to speed up screening of C&S; Consider outsourced laboratory-scale product development and validation, or sub-licensing of C&S from outside sources

2. Conceptual design of the envisioned commercial process. Utilize available laboratory data from the developed C&S to conceptualize a desired commercial process. Involve chemical process engineers early at this stage

3. Pilot and commercial scale product (C&S) manufacturing. Consider outsourced manufacturing of the developed C&S

4. Pilot-plant process development and basic design. Use a pilot plant as a scale-down of the envisioned commercial plant — the primary objective is to collect sufficient data for scaleup. Also, consider skipping pilot plants

5. Pilot-plant detailed design and construction. Consider outsourcing pilot-plant design and construction

6. Pilot-plant process validation. Involve not only engineers but also researchers directly. Consider outsourcing pilot plant validation

7. Commercial-process development and basic design. Scaleup to a commercial plant based on data from the pilot plant, and re-check scaleup issues

8. Commercial-process detailed design and construction. Consider outsourcing commercial-process design and construction

9. Commercial process demonstration and validation. Con-

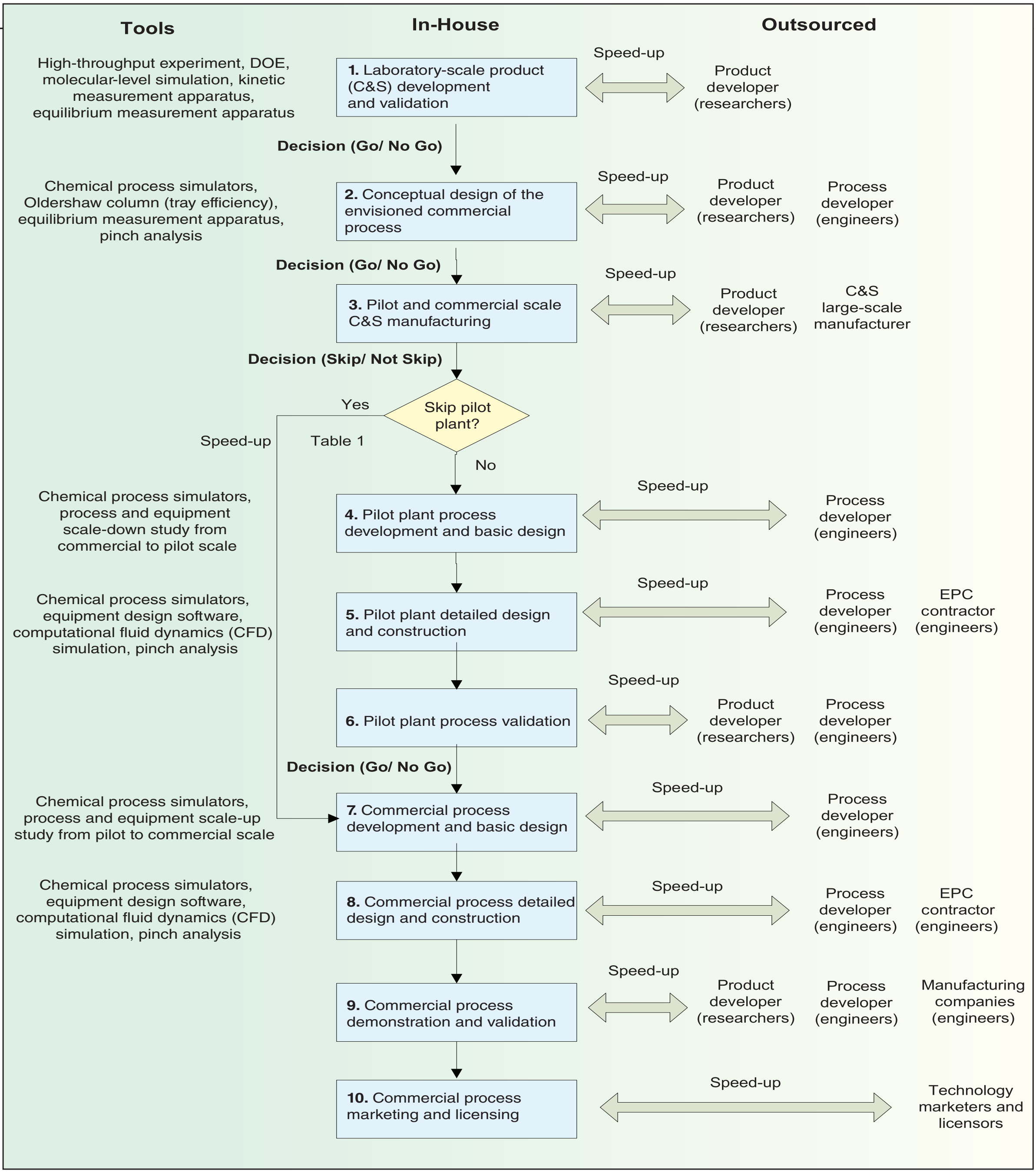


FIGURE 1. Strategies to speed up process development projects are presented visually in this diagram

sider a partnership with manufacturing companies

10. Commercial process marketing and licensing. Consider outsourcing process marketing and licensing

STRATEGIES

Systematic strategies are required in all stages of process development to speed up a project. The most important thing is to always begin with the end by having the desired commercial process concept in mind. Project goals and objectives should be clarified from the beginning. After conceptualizing the commercial process, tactics to speed up the project in each stage can then be defined clearly. Effective and strategic use of both in-house and external resources are key to success. Before spending your own resources on something you are unfamiliar with in product and process development, always consider an option to outsource some parts of a project to a qualified third party.

Four simple strategies can be used to speed up and increase the success rates of projects. These steps include the following:

A. Assess your project goals

B. Assess your manpower resource characteristics

C. Assess your new process and identify key issues
D. Plan your acceleration strategies early with the end in mind

These four strategies are explained in the following sections.

Assess your project goals

In order to speed up your project, it is necessary to make the final goals of the project clear to the team. In general, there are three kinds of project goals:

Product development. The goal of research can be purely to develop new promising C&S that might have the potential to be further developed into a commercial process. For example, a propane dehydrogenation catalyst was developed by one company and sub-licensed to another company to develop a new process that could use the developed catalyst successfully under various constraints, such as catalyst deactivation concerns and on-line regeneration requirements and so on.

The benefits in this situation are then shared between the new C&S and new process developers. A major advantage of this approach is reduced time to commercialization because the R&D scope is reduced.

However, disadvantages of this approach include reduced benefits to the C&S developer and increased risks associated with a potentially unqualified process developer, and difficult know-how management and transfer between the two parties.

There are more complicated cases where the catalyst developers on a laboratory-scale and catalyst manufacturers on a commercial-scale belong to different companies. The pilot-plant developer and commercial-process developer can also be members of different companies. In all of these cases, the most important thing is to make it clear from the beginning of a project which parties are to be involved in the commercialization of this process so that resources can be allocated to the project appropriately.

Process development. The goal of research can also be purely to develop a new process without developing new C&S. It may be a new process configuration and concept improvement without new C&S, or a new process that utilizes new C&S developed by another party.

For instance, let's say a process development company purchases a license to use a new propane dehydrogenation catalyst from another company, and develops a new process based on that catalyst. The process developer can become a technology licensor and license out the new process under its own tradename, but clients need to buy the new catalyst either directly from the catalyst manufacturer or via the technology licensor.

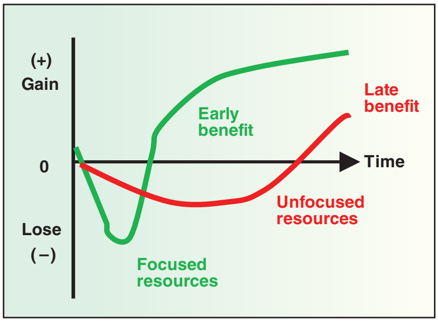


FIGURE 2. This graphical presentation demonstrates that accelerating new process and product development gives earlier and higher project-life benefits

The benefits are then shared between the new C&S and new process developers. Advantages and disadvantages are similar to those mentioned above.

Combined product and process development. A single project can combine both new C&S and new process development. For instance, a company may develop a new catalyst at laboratory scale and then go further in developing its own proprietary process to use the newly developed catalyst.

Major advantages of this approach are maximized benefits from licensing and commercializing the process. Disadvantages are significantly more time and manpower resources required, and more risks involved in the commercialization if that company lacks expertise in either new C&S or new process development. There are few companies really competent in both C&S and process development at the same time. Research institutes, universities and some chemical companies are more specialized in new C&S development, whereas technology licensing companies tend to be more specialized in new process development.

Assess manpower resources

It is of great importance to assess manpower resource characteristics when selecting a project goal to be pursued. Let your project economics help guide manpower resource deployment (increase and adjust manpower to accelerate high-impact projects).

Is the majority comprised of researchers or engineers? If researchers form the majority, it is possible to speed up projects by focusing on new C&S development. Researchers are good at developing new C&S at laboratory scale, but tend to lack know-how on how to commercialize them.

If engineers form the majority, it is possible to speed up projects by focusing on new process development.

Is the majority comprised of chemists or chemical engineers? If the majority is chemical engineers, it is possible to speed up projects by focusing on new process development because chemical engineers are good at conceptualizing a process scheme to commercialize the developed C&S, while they may lack the strong chemistry background required to develop innovative and unique C&S.

On the other hand, chemists are good at developing new C&S because they understand the chemistry and mechanisms involved very well, but are often weak at process commercialization and scaleup.

It is thus imperative to have a well-balanced team of chemists and chemical engineers, depending on the project goals. Conversely, it is important to make project goals clear from the beginning in order to effectively allocate resources to the project.

Integrated project team for process development. For combined product and process development, it is important to have an integrated team of researchers and engineers, chemists and chemical engineers.

To speed up a project, it should be made clear from the beginning of a project what parties are required for process development. For example, if a qualified, outsourced pilot-plant contractor is to be used, it is not nec-

TABLE 1. GUIDELINE FOR A DECISION TO SKIP PILOT PLANTS		
Unit Operation	**Can pilot plants be skipped?**	**Comments**
Distillation	Usually yes, but pilot plants are sometimes needed to get tray efficiency or height equivalent to a theoretical plate (HETP) data	Sometimes required for making product samples to customers. Foaming should be checked when skipping pilot plants
Fluid flow	Usually yes for single phase. Frequently no for multiphase flow and polymer systems	Some polymer flow properties are very difficult to predict, especially viscosity versus temperature
Heat exchangers, evaporators, reboilers, condensers	Usually yes, unless there is a possibility of fouling, coking and polymerization	Sometimes required for new unconventional types of heat exchangers only
Reactors	Frequently yes for simple types of reactors, such as batch, continuous stirred-tank reactors (CSTR) and fixed-bed plug-flow reactors (PFR)	Scaleup from laboratory sometimes justified for homogeneous or single-phase heterogeneous heat-neutral reactions
Dryers	Frequently no. Should pilot in equipment of a similar type to the commercial plant	Usually vendor equipment
Extraction	Frequently no. Should pilot in equipment of a similar type to the commercial plant	Usually vendor equipment
Crystallization	Frequently no. Should pilot in equipment of a similar type to the commercial plant	Usually vendor equipment
Solids handling	Frequently no	Usually vendor equipment
Hybrid separation-reaction (such as reactive and extractive distillation)	Almost always no	Usually proprietary equipment
Processes with impurities and recycle streams	Sometimes no, if undesired impurities can accumulate due to process recycles, or if unable to check effects at laboratory scale	Pilot plant should be designed to incorporate effects of impurities and recycle streams

essary to develop an integrated team of engineers in-house, and only process engineers may suffice. However, if a pilot plant is to be designed and built essentially by an in-house engineering team, it is often necessary to have various engineering disciplines in-house, such as instrumentation engineers and mechanical engineers.

Forming a strategic alliance with complementary partners is a key to speeding up process development projects. Understanding the strengths and weaknesses of an existing project team is indispensable to creating a successful partnership to speed up a project significantly. The only drawbacks are fewer shared benefits and the extra risk of ineffective collaboration.

Assess the process

Understanding reactions and phenomena involved during process development is a key, not only to the project's success, but also to speeding up process development.

Reactions — single phase or multiphase; homogeneous or heterogeneous; reaction mechanism. Simple reactions in simple reactor types can significantly reduce the time required for process development. For example, a single-phase reaction in a fixed-bed reactor can be much more confidently scaled up than a multiphase reaction in a moving-bed reactor.

Reactions that may allow skipping certain steps — such as pilot plant validation — are those that take place in a single or homogeneous phase, those with high selectivity and consequently few byproducts, those with a simple reaction mechanism and those that are relatively heat neutral (Table 1). Ref. 6 provides useful insights on how to scale up a fixed-bed reactor directly from laboratory to commercial scale by verifying reaction-rate-limiting steps from laboratory experiments and use those data for scaleup.

However, this method neglects effects of heat transfer and is thus not applicable to highly endothermic or exothermic reactions. Ref. 7 provides guidelines in judging whether to scale up batch processes directly from laboratory to plant scale.

Reactions that frequently require pilot plant validation are those that involve complex multiple or heterogeneous phases (for example, an air-bubbling reactor), and have many side reactions (for example, thermal cracking), complex mechanisms, and significant exothermicity or endothermicity (such as in dehydrogenation). These reactions often dictate the need for kinetic studies and detailed reactor modeling. Reactions that involve multiphase operation, such as bubble-column and fluidized-bed reactors, often require pilot plant validation to collect sufficient data for scaleup to a commercial process.

Separations — single phase or multiphase. Chemical processes generally require numerous separations to purify the final products. Most separation operations separate desired products based on equilibrium conditions. Thus, accurate thermodynamic-equilibrium data are necessary for scaling up the separation operations correctly and confidently.

Some conventional separation operations, such as distillation, allow skipping pilot plant validation. Vapor-liquid equilibrium (VLE) and tray efficiency data can be obtained from laboratory scale experiments, and heat-and-material balance models can be developed from those laboratory data. The number of trays, reflux rates, and vapor-liquid loading for tray hydraulics calculations can be obtained from the models and used to scale up.

However, other separation operations, such as extraction, drying, crystallization, solids handling and most hybrid operations (such as reactive distillation) almost always require pilot plants unless well-proven vendor equipment for a similar service is used (Table 1).

One of the most powerful concepts in separation design is the residue curve. This curve describes the equilibrium relationships for ternary mixtures and the change of the liquid residue composition in a one-stage batch distillation of the mixture. Multiple curves for a single system, called residue curve maps, provide a rapid, graphical means to visualize separation possibilities and constraints of azeotropic ternary systems. To accelerate process development, it is helpful to have an expert on the residue curve who can conceptually design the separation operations.

Combined reactions and separations. It is wise to consider reactions and separations together, since total investment and operating costs (termed "combined costs") are the sum of total costs from both reaction and separation sections. Separately optimizing reaction and separation sections tends to lead to suboptimal solutions. For example, increasing reactor size and energy consumption to achieve higher conversion and thus higher purity of desired products can sometimes significantly reduce combined costs of the downstream separation section [*2*].

Heat transfer — single phase or multiphase. Heat transfer is one of the most common unit operations in both reactions and separations. Conventional heat-transfer-equipment design (for example evaporators, reboilers and condensers) is usually well understood, thereby allowing pilot plant validation to be skipped. For example, shell-and-tube heat exchangers and double-pipe heat exchangers are well understood, and only thermodynamic and properties data are needed to design and scale them up. Commercial software, such as that from Heat Transfer Research Inc. (HTRI) called HTRI Xchanger Suite, is also rigorous enough to design them confidently.

However, unconventional types of heat transfer equipment often require pilot plant validation for the first unit of its kind. For example, a heat transfer operation that involves simultaneous mass transfer (for example, an ethylene-plant quench oil tower), unconventional types of heat exchangers, and unfamiliar multiphase flow regimes frequently require a pilot plant to collect data for commercial scaleup.

Materials transfer — fluids or solids; single-phase or multiphase. In general, solids handling and transfer are more problematic than fluids transport. In contrast to fluids, which are typically transferred through pipelines with pumps or blowers, solids are carried or pushed along by various kinds of conveyer equipment. Solids in granular form are also transported as slurries in inert liquids, or as suspensions in air (pneumatic conveying) or another gas.

Multiphase transfer poses more challenges than single-phase transfer. In multiphase flow, it is typically desirable to design a flow regime to be annular and avoid a slug-flow regime. Unit operations involving solid and multiphase transport tend to require pilot plant validation due to their complexity. During the conceptual design stage of a commercial process, the type of materials transfer to be used in the process should be addressed.

Safety. Safety aspects must be considered in as early a stage as possible, even before the Hazop (hazard and operability) review. Failure to do so may result in project delays.

For example, a hydrocracking process requires special high-pressure and high-temperature safety considerations, such as breech-lock type heat exchangers, and emergency reactor quenching and depressuring because of highly exothermic hydrogenation reactions taking place at high pressure and temperature (up to 200 barg and over 400°C). Low-density polyethylene (LDPE) plants operate the polymerization reactor at 2,500 barg pressure or more, thus requiring a special concrete enclosure built around the LDPE reactor.

Environmental. One of the most common mistakes is to ignore environmental aspects of a project in an early stage. Byproducts from a reaction are potential wastes that need treatment and disposal. Effluent waste streams should be considered at an early stage of a project. An environmental impact assessment (EIA) process can significantly delay projects when process developers fail to foresee or predict environmental impacts before they are addressed by the EIA approval committee. Thus, considering environmental aspects of both pilot and commercial plants as early as possible in a project can speed up a project and avoid unnecessary delays.

Metallurgy. Special metallurgy requirements can sometimes delay process development projects. Inappropriate specification of the materials of construction from the beginning can later increase project costs and even invalidate the process design. For example, special metallurgy (such as specific grades of stainless steels and alloys) often requires particular welding procedures and expertise that may make it too expensive or difficult to find a fabricator locally.

Over-specifying materials of construction can also make a promising process seem economically infeasible. It is thus recommended to have a metallurgy consultant either in-house or outsourced to consult on metallurgy issues.

Additional potential issues in process development. Other potential issues that may need to be considered are mentioned here:

- Unclear or unachievable product specifications
- Sophisticated process control strategies
- Lack of process simulation capability
- Lack of key physical properties
- Identification of "black boxes" or unknowns
- High pressure and temperature systems
- Sophisticated mechanical design

Plan strategies early

Companies that plan acceleration strategies early with the end in mind have greater chances of success. Early planning allows one to foresee potential problems along the way toward process commercialization more clearly, and it allows one to utilize internal and external resources more effectively.

Laboratory-scale new product (C&S) development and validation. To speed up new C&S development, two major tools are recommended: high-throughput screening and design-of-experiments (DOE). When it is inevitable to investigate various combinations of catalysts (such as catalytic element types, compositions or morphology) to screen and select for further testing, high-throughput screening is an efficient tool to help. Although the accuracy of how closely the high-throughput screening apparatus simulates the real commercial reactor conditions may be arguable, the technique nevertheless provides useful preliminary comparisons for different compositions and formulas of catalysts.

DOE is another tool to speed up new C&S development because it provides a systematic method to minimize the number of experiments needed to obtain the same results with the same level of confidence and coverage that one might obtain from many more experiments without using DOE. Not all researchers need to be specialized in DOE, but it is helpful to have someone who is knowledgeable about DOE and can advise researchers how to design experiments efficiently. In addition, smart use of other tools, such as computer molecular simulation and commercial kinetic-measurement apparatus can also help accelerate the process development.

Another way to speed up new C&S development is by outsourcing or purchasing a product license directly from product developers. Numerous research institutes and universities have developed promising C&S that process developers can adopt to a commercial process using available laboratory and pilot plant data.

In most cases, however, process developers may not obtain enough information from the C&S developers because of know-how secrecy issues, thus making it difficult for process developers to scale up the process confidently. To avoid this issue, process developers must understand parameters that are key to the success of scaleup and convince the C&S developers to conduct additional tests that will answer those scaleup issues.

Conceptual design of the envisioned commercial process. C&S developers (researchers) often have chemistry or materials-science backgrounds, and may not be knowledgeable about process scaleup. One of the most common mistakes is to start the conceptual design of the envisioned commercial process too late in a project.

For example, a researcher may test a new catalyst's performance and optimize operating conditions (such as temperature and pressure) in a batch laboratory reactor, without realizing that the commercial scale reactor will not be batch. If the commercial process will use a fluidized bed reactor, for example, the flow regimes and rate-limiting steps are different from a batch reactor, and the generated laboratory data may be misleading or irrelevant to the design of the pilot plant and commercial process.

To speed up this step, it is a good practice to involve chemical process engineers early and encourage an engineering study between the C&S innovator and process developer [*11*] in order to conceptualize the commercial process early so that laboratory and pilot-plant validation strategies can be adjusted to better match the envisioned commercial process.

Pilot- and commercial-scale product (C&S) manufacturing. Major issues related to this step are mass production in tons instead of kilograms, lower-purity starting materials, catalyst attrition and crush strength.

To speed up this step, if catalyst developers (formulators) lack the know-how to manufacture catalysts on a large scale, it is a good strategy to form a partnership with a well-proven catalyst manufacturer to scale up the catalyst production.

Pilot-plant process development and basic design (scale-down from commercial to pilot plants). A pilot plant is an important tool to obtain technical data and investigate effects of feed impurities and process recycle for a confident scaleup. Thus, pilot plants should be a scale-down of the envisioned commercial plants instead of a scaleup of the laboratory scale [*5, 11*]. It is more practical to save time and money by selecting only key critical equipment systems to pilot, rather than including all commercial process equipment into a pilot plant.

To speed up this step, it should be carefully assessed whether a pilot plant is really necessary or can be skipped (Table 1). Pilot plants are occasionally used just for producing product samples for clients to test and evaluate. Pilot plants are sometimes needlessly used for some purposes that can be achieved at laboratory scale or by good process modeling. For example, reactor kinetics can be done by laboratory kinetic measurement, and heat-and-material balances can be obtained using reliable thermodynamic data and properties from laboratory experiments or literature data without using pilot plants.

Pilot-plant detailed design and construction. Apart from previously published strategies to fast-track pilot plant projects [*8–10*], key strategies to speed up pilot plant design and construction include the folowing:

- Have an integrated project team in-house that includes all necessary engineering disciplines
- Hire a pilot plant contractor that

has abundant experience in designing and commissioning similar pilot-plant processes. For example, do not hire a pilot plant contractor who has designed only fixed bed reactors to design fluidized bed reactors

- Let the design team work under the same roof with a pilot plant fabricator in order to be able to respond to unplanned design and fabrication issues without delays
- Make as small and simple a pilot plant as is practical for scaleup purposes. For example, some companies build their pilot plants using simple tubing as lines and large-diameter pipes as vessels, which are then supported by nuts and bolts on vertical grating walls. Instruments are connected by tube fittings, thus simplifying the construction and allowing easy assembly and disassembly. Multi-tubular reactors are typically scaled up from only a single "show tube" representing actual operating conditions of thousands of tubes in the commercial reactor

Pilot-plant process validation. It is important to clearly identify and communicate pilot-plant testing objectives to the project team to eliminate repeated and unnecessary work. To speed up this step, it is desirable to educate pilot plant operators well in advance on the commissioning and testing plan, as well as continue to involve product developers (researchers) in process troubleshooting and important decisions during the pilot-plant testing program.

Commercial process development and basic design (scaleup from pilot to commercial plants). This step can be accelerated considerably if the pilot plant has been scaled down properly to collect valid necessary data for scaleup and if there have been no major changes to the conceptualized commercial process design. To further speed up this step, consider use of an outsourced process developer who has proven know-how on scaleup of similar processes, especially when experienced in-house resources are unavailable. The greater the quality and the larger the quantity of the scaleup data collected during the pilot-plant process validation, the faster the progress of this step and the higher the chances of success.

Commercial-process detailed design and construction. The considerations to speed up this step are similar to those in pilot-plant design and construction.

Commercial-process demonstration and validation. For the first process of its kind, it is often necessary for process developers to build their own demonstration plants to convince potential customers that the process can be operated commercially and successfully without unforeseen troubles. To speed up this step, process developers may form a partnership with manufacturing companies who have similar types of processes and equipment that can be used for the demonstration plants, or those who are willing to share the benefits if the process can be successfully commercialized.

Commercial-process marketing and licensing. Marketing and licensing of the commercial process can be a problem for inexperienced product and process developers, especially for manufacturing companies carrying out their own in-house R&D. It is worth considering a partnership with a company that has considerable experiences in commercial-process marketing and licensing to save marketing and licensing costs and reduce risks. By collaborating with an experienced, technology marketing and licensing company, a process-developer company can learn what the key issues for marketing and licensing are. Moreover, the process-developer company can hire fewer people and still be successful in marketing and licensing. However, major disadvantages are benefit sharing and risks of know-how losses despite a well-written confidentiality agreement.

Concluding remarks

All strategies above have been extracted from validated technical references and years of the author's experience in process development. The ideas of conceptualizing commercial process design early and designing a pilot plant based on a scale-down of a commercial plant are in good agreement with references [*5,11*] and also with actual observations of the importance of beginning with the end in mind. There was a real case where commercialization of an olefins polymerization reactor was significantly delayed because pilot plant data and collected laboratory data were inapplicable as they did not represent or reflect the real phenomena well enough to be used as valid data for reactor scaleup. The researchers and pilot plant developers failed to think beforehand about how the commercial polymerization reactor would look and what the commercial reactor size and internal flow regime would be. ■

Edited by Dorothy Lozowski

References

1. Sinclair, G., Allocate R&D Resources Effectively, *Chem. Eng. Prog.*, February 1999.
2. Kelkar, V. V., others, A strategy for excellence in process development, *Chem. Eng. Prog.*, October 2008.
3. Mueller, J., others, Integrated product teams for process development, *Chem. Eng. Prog.*, July 2005.
4. Mukesh, D., Succeed at Process Development, *Chem. Eng. Prog.,* February 1999.
5. Bisio, A., others, "Scale-Up of Chemical Processes," John Wiley and Sons, 1985.
6. Worstell, J. H., others, Improve Fixed Bed Reactor Performance without Expenditure, *Chem. Eng. Prog.,* January 2004.
7. Leng, R. B., Scale-Up Specialty Chemical Processes Directly, *Chem. Eng. Prog.,* November 2004.
8. Kenat, T. A., Use Your Pilot Plant as a Process Design Tool, *Chem. Eng. Prog.,* February 1999.
9. Martin, P., others, Fast-Track Your Pilot Plant Projects (Part 1), *Chem. Eng. Prog.,* January 2005.
10. Lalla, L. D., Don't Apply Commercial Plant Specifications to Pilot Plants (Part 2)," *Chem. Eng. Prog.,* February 2005.
11. Boundy, R. H. and Amos, J.L., "A History of Dow Chemical Physics Lab," Marcel Dekker Inc., 1990.

Author

Wiroon Tanthapanichakoon is a process design engineer working for the olefins Research and Technology (R&T) office of SCG Chemicals, Co. Ltd. (Thailand; Email: wiroont@scg.co.th or twiroon@gmail.com; Phone: +66-38-911-240 or +66-83-177-8108). He is involved mainly in process and equipment design, as well as basic engineering for research and development projects for SCG Chemicals. He has several years of experience as a process engineer with an Exxon Mobil subsidiary refinery in Thailand, and as a process design and energy improvement engineer with SCG Chemicals. He obtained his B.E. and M.E. degrees in chemical engineering from Kyoto University, Japan. He is a professional licensed engineer in Thailand and has authored several technical articles.

Fractionation Column

Opportunities for Recent Grads

There was genuine excitement at the November 14 and 15 ChemInnovations event held in New Orleans. This was especially true at the Plant Managers Roundtable that was moderated by Rebekkah Marshall. On stage with Rebekkah were Jim Armstrong of Rhodia, Inc., Paresh Bhakta of Celanese Ltd. and Jim Hull of Georgia Gulf Chemicals and Vinyls, LLC. All three gentlemen are very experienced plant managers, all with international experience. All three seemed to be in agreement regarding the answers to the questions that were posed to them.

Low natural gas prices, now and in the near future, have changed everything — especially in the U.S.! Personally, I have not seen anything like it in my 38 years as a practicing engineer. Natural gas is both a feedstock and an energy source and therefore, low natural-gas prices provide a two-fold benefit to U.S. chemical producers. Chemical plant expansions are being planned for many states, especially those on the Gulf Coast. Engineers of all disciplines are in great demand, especially considering that the mass baby-boomer retirement exodus has already begun. According to the on-stage plant managers, engineers with five years of experience are particularly valuable right now and receive two or three telephone calls from headhunters every day. In Baton Rouge, there are highway billboards looking for engineers. (Where I live, most of the billboards state something like "LaQuinta Inns & Suites are Pet Friendly!")

Regarding the next crop of B.S. graduates in May, the plant managers had comments and advice. A GPA (grade point average) of 2.5 is very acceptable. An M.S. degree is of marginal value to a plant engineering position; likewise a P.E. license. Engineering companies often feel very differently about P.E. licenses. Military experience augments a resume, and the managers appreciate the "Yes, sir, can do" attitudes of veteran applicants, but those applicants must understand that those words are rarely spoken to freshman engineers by senior operation technicians. Similarly, those technicians respond poorly to arrogance (and self-confidence that grossly exceeds successful job experiences). For those technicians, engineers of all experience levels need to be effective communicators. In and out of control rooms, text messages are not as effective as telephoning, which is not as effective as face-to-face conversations. The plant managers were unhappy with the writing abilities of the last few batches of B.S. graduates; this applies to both emails and reports.

Regarding the resumes of recent B.S. recipients, the plant managers stated that they look favorably on work experience — for instance, summer jobs and part-time jobs during school years. Such experience provides invaluable lessons regarding working for and with people. School laboratory group experiences do not suffice.

The plant managers' enthusiasm was excessively infectious. I dyed my gray hair. I moved to Louisiana. I enrolled in LSU's chemical engineering B.S. program. I am taking an online class entitled Resume Writing and Interview Skills for septegenarians. My wife Jacky is not as excited about my new career path as I am. She says, "There's a certain Déjà vu to it — don't ya think?" ■

Mike Resetarits

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

PRODUCT SHOWCASE

SOFTWARE

CONSULTING

NEW & USED EQUIPMENT

Remove Tramp Metals

ProGrade Magnets
Low Cost • High Power

FF5
Metal Separator
- Detects & Rejects:
  - Aluminum
  - Brass/Copper
  - Steel
  - Stainless

ERIEZ

call 888-300-3743
visit www.eriez.com

Circle 243 on p. 60 or go to adlinks.che.com/45769-243

HEAT EXCHANGERS

INDUSTRIAL HEAT EXCHANGERS
XCHANGER
(952) 933-2559 info@xchanger.com

Circle 249 on p. 60 or go to adlinks.che.com/45769-249

WABASH SELLS & RENTS

Boilers
20,000 - 400,000 #/Hr.
Diesel & Turbine Generators
50 - 25,000 KW
Gears & Turbines
25 - 4000 HP
We stock large inventories of:
Air Pre-Heaters • Economizers • Deaerators
Pumps • Motors • Fuel Oil Heating and Pump Sets
Valves • Tubes • Controls • Compressors
Pulverizers • Rental Boilers & Generators
24/7 Fast Emergency Service
800-704-2002
Phone: 847-541-5600 Fax: 847-541-1279
www.wabashpower.com

wabash POWER EQUIPMENT CO.
444 Carpenter Ave., Wheeling, IL 60090

Circle 248 on p. 60 or go to adlinks.che.com/45769-248

DUAL SHAFT MIXERS

New 50, 100 & 200 gal. mixers in stock!

Scan to learn more & get a free quote.

Free Tag Reader: http://gettag.mobi

1-800-243-ROSS
www.DualShaftMixers.com
ROSS

Circle 247 on p. 60 or go to adlinks.che.com/45769-247

GET CONNECTED TODAY
www.che.com

BOILERS

Boilers (various styles & sizes)
Boiler Parts & Accessories
Burner Management
Chillers
Combustion Controls
Construction Services
Deaerators
Design & Build
Diesel Generators
Economizers
Engineering
Fuel Systems
Pumps
Water Treatment

Rent
Lease
Sell

Mobile Boilers
(10HP - 250,000PPH)

Rental Diesel Generators
(125KW - 2200KW)

EMERGENCY SERVICE 24HR

Chillers
(Water Cooled: 75-1000 tons
Air Cooled: 75-400 tons)

Please contact us to inquire on our extensive line of industrial Power Plant Equipment available from stock

INDECK
847.541.8300 / 800.446.3325
info@indeck-power.com
www.indeck.com

Circle 246 on p. 60 or go to adlinks.che.com/45769-246

BUYER'S GUIDE LISTING:

Dickow Pump Co.
1738 Sands Pl. SE #200, Marietta, GA 30067 USA
Phone: 770-952-7903 **Fax:** 770-933-8846
Email: info@dickow.com **Web:** www.dickow.com
Pumps: centrifugal, multistage;
Pumps: magnetically driven; Pumps: leakproof;
Pumps: nickel-based alloy; Pumps: stainless steel

Circle 242 on p. 60 or go to adlinks.che.com/45769-242

GET CONNECTED TODAY
www.che.com

RECRUITMENT

Production Manager/Plant Supervisor

for a medium sized manufacturer of specialty chemicals.
Function: Coordination of all production, maintenance, safety and compliance activities; Management of the 24/7 team;
Reporting (KPI's) directly to the CEO.
Requirements: BS in Chemical / mechanical engineering;
min. 5+ (10+) years experience in chemical production environment.
Location: Alabama Gulf Coast
Please forward Resumé, availability and Salary history to:
productionmanager3@gmail.com

Circle 250 on p. 60 or go to adlinks.che.com/45769-250

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

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

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

Name ____________________ Title ____________________

Company ____________________

Address ____________________

City ____________ State/Province ____________ Zip/Postal Code ____________

Country\ ____________ Telephone ____________ Fax ____________

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

FREE PRODUCT INFO

(please answer all the questions)

YOUR INDUSTRY

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

JOB FUNCTION

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

EMPLOYEE SIZE

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

YOU RECOMMEND, SPECIFY, PURCHASE

(please circle all that apply)

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

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

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

Fax this page back to 800-571-7730

ADVERTISING SALES REPRESENTATIVES

North America

Eric Freer, **District Sales Manager**
Chemical Engineering
11000 Richmond Ave, Suite 690, Houston, TX 77042
Tel: 713-343-1904 *E-mail:* efreer@che.com
Alabama, Alaska, Canada, Connecticut, Delaware, Florida, Hawaii, Idaho, Kentucky, Maine, Maryland, Massachusetts, Michigan, Mississippi, Montana, Nebraska, New Hampshire, New Jersey, New York, North & South Carolina, North & South Dakota, Ohio, Oregon, Pennsylvania, Rhode Island, Tennessee, Utah, Vermont, Virginia, Washington, D.C., West Virginia, Wyoming, Latin America

Jason Bullock,
District Sales Manager
Chemical Engineering
8325 Broadway, Ste. 202/PMB 261
Pearland, TX 77581
Tel: 281-485-4077; Fax: 281-485-1285
E-mail: jbullock@che.com;
Arkansas, Arizona, California, Colorado, Georgia, Kansas, Louisiana, Missouri, New Mexico, Nevada, Oklahoma, Texas, Washington

Dan Gentile
District Sales Manager
Tel: 512-918-8075
E-mail: dgentile@che.com
Indiana, Illinois, Iowa, Minnesota, Wisconsin

Diane Hammes
Inside Sales Manager
Chemical Engineering;
11000 Richmond Ave, Suite 690,
Houston, TX 77042
Tel: 713-444-9939
E-mail: dhammes@che.com
Product Showcase, Literature Reviews, Classified Display Advertising

International

Petra Trautes
Chemical Engineering
Zeilweg 44
D-60439 Frankfurt am Main
Germany
Phone: +49-69-58604760
Fax: +49-69-5700-2484
Email: ptrautes@che.com
Austria, Czech Republic, Benelux, Eastern Europe, Germany, Scandinavia, Switzerland, United Kingdom

Dipali Dhar
Chemical Engineering
88 Pine Street, 5th floor, New York, NY 10005
Tel: 718-263-1162
E-mail: ddhar@accessintel.com
India

Katshuhiro Ishii
Chemical Engineering
Ace Media Service Inc., 12-6, 4-chome
Nishiiko, Adachi-ku, Tokyo 121, Japan
Tel: 81-3-5691-3335; Fax: 81-3-5691-3336
E-mail: amskatsu@dream.com
Japan

Ferruccio Silvera
Chemical Engineering
Silvera Pubblicita
Viale Monza, 24 Milano 20127, Italy
Tel: 39-02-284-6716;
Fax: 39-02-289-3849
E-mail: ferruccio@silvera.it/www.silvera.it
Andorra, France, Gibraltar, Greece, Israel, Italy, Portugal, Spain

Rudy Teng
Sales Represntative
Chemical Engineering;
Room 1102 #20 Aly 199 Baiyang Road
Pudong Shanghai 201204
China
Tel: +86 21 50592439
Fax: +86 21 50592442
MP: +86 13818181202
E-mail: rudy.teng@gmail.com
Asia-Pacific, Hong Kong, People's Republic of China, Taiwan

Advertisers' Index

Classified Index February 2013

See bottom of next page for advertising sales representatives' contact information

Send Advertisements and Box replies to: Diane Hammes

Chemical Engineering, 11000 Richmond Ave, Houston, TX 77042

E-mail: dhammes@che.com Tel: 512-250-9555

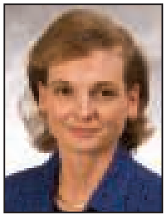
FEBRUARY WHO'S WHO

Williamson

Raza

Lumbard

Amsbaugh



Juhasz

Bruno Morel becomes CEO, and *Frédéric Raynal* becomes chief technology officer and vice president of engineering, at **Alchimer SA** (Massy, France), a provider of nanometric deposition technologies for advanced 3D packaging.

Philip Tilston becomes chief financial officer of **Wall Colmonoy Ltd.** (Madison Heights, Mich.), a maker of surfacing alloys and precision components.

Steven Winchester is named CEO of **MaxWest Environmental Systems** (Sanford, Fla.), a maker of biogasification systems for wastewater treatment.

SmartKem Ltd. (Manchester, U.K.), a developer of high-performance organic semiconductor materials makes several appointments: *Hugh Williamson* becomes chief operating officer, *Muhammad Raza* and *Keith Lumbard* join the company as scientists, *Bill Freer* is chairman and *Gary Tam* is business development director.

Brooks Instrument (Hatfield, Pa.), a provider of flow, pressure, vacuum and level solutions, appoints *Scott Amsbaugh* general manager.

Specialty chemicals maker **Sartomer USA LLC** (Exton, Pa.) names *Nikola Juhasz* senior director of research and development, and *Ken Earle* global supply chain director.

Engineering, construction and commissioning specialist **Integrated Project Services** (IPS; Lafayette Hill, Pa.) names *John Panebianco* director of process engineering. ■

Suzanne Shelley

BUSINESS NEWS

PLANT WATCH

Lonza to expand ADC manufacturing capacity

January 8, 2013 — Lonza (Basel, Switzerland; www.lonza.com) plans to invest 14 million Swiss francs (CHF; about $15 million) to expand antibody drug conjugate (ADC) manufacturing capacity in Visp, Switzerland. Oncology therapeutics including ADCs represent one of the fastest growing segments of the pharma and biotech industry. The expansion of the ADC facility, which is expected to be complete in the second quarter of 2014, will double the existing large-scale manufacturing capacity in Visp.

Technip awarded FEED contract for ammonia plant in Louisiana

January 3, 2013 — Technip (Paris, France; www.technip.com) was awarded by The Mosaic Co. (www.mosaicco.com) the front-end engineering and design (FEED) contract, as well as preparation of the corresponding engineering, procurement and construction (EPC) proposal, for a new ammonia plant under consideration by the global crop-nutrient company. Mosaic's preference is to locate the proposed plant adjacent to the company's existing Faustina fertilizer manufacturing operations in St. James Parish, La. It would have a capacity of 2,200 metric tons (m.t.) per day. The proposed design would feature Haldor Topsøe A/S' (Lyngby, Denmark; www.topsoe.com) proprietary ammonia-process technology that Technip has successfully engineered and constructed. The FEED and corresponding EPC are targeted for completion by mid-2013.

BASF increases global capacity for hexanediol

January 3, 2013 — BASF SE (Ludwigshafen, Germany; www.basf.com) will increase its global capacity for manufacturing the chemical intermediate 1,6-hexanediol (HDO) by more than 20% to more than 50,000 ton/yr by 2014. For this purpose, the company will invest more than €30 million to further optimize its production processes, carry out various infrastructure projects and enhance its logistical processes. BASF operates HDO production facilities at its sites in Freeport, Tex., and Ludwigshafen, Germany.

Evonik expands U.S. production of precipitated silica

December 20, 2012 — Evonik Industries AG (Essen, Germany; www.evonik.com) plans to increase its production capacities for precipitated silica at its site in Chester, Pa. by around 20,000 m.t./yr. The new facility, which received an investment in the lower double-digit million euros range, is scheduled to become operational in 2014. The capacity expansion in Chester underscores the plans of the Evonik Group to expand its global silica capacities by about 30% over the level of 2010 by 2014.

New acrylic acid plant planned in the Republic of Bashkortostan

December 19, 2012 — Mitsubishi Heavy Industries, Ltd. (MHI; Tokyo, Japan; www.mhi.co.jp) and Sojitz Corp., jointly with Renaissance Construction (RC), have received an order from JSC Gazprom Neftekhim Salavat (GNS) of the Republic of Bashkortostan, Russian Federation, for a project to construct a new acrylic acid plant with process technology licensed by Mitsubishi Chemical Corp. (MCC). The plant is planned to produce 80,000 m.t./yr of acrylic acid, 80,000 m.t./yr of butyl acrylate and 35,000 m.t./yr of glacial acrylic acid, and it is expected to reach its projected capacity in 2015.

Caloric to supply hydrogen-generating plant to the Czech Republic

December 19, 2012 — Caloric Anlagenbau GmbH (Gräfelfing, Germany; www.caloric.com) has won a contract for a hydrogen-generating plant with a capacity of 2,000 Nm^3/h based on naphtha feed stock. The hydrogen unit will be located in the Czech Republic and will provide hydrogen to a benzene production unit. The plant design will follow Caloric's expertise in highly efficient and customized concepts. The operation of the plant will start in mid-2013.

Toyo wins fertilizer plant order in Indonesia

December 18, 2012 — The consortium of Toyo Engineering Corp. (Toyo; Chiba, Japan; www.toyo-eng.co.jp) and PT Rekayasa Industri (Rekind) has been awarded a fertilizer project from the Indonesian fertilizer company, PT Pupuk Sriwidjaja Palembang (PUSRI). The project, named "PUSRI IIB," is to be constructed in Palembang of South Sumatra, Indonesia. The contract is for EPC services for the facilities to produce 2,000 ton/d of ammonia and 2,750 ton/d of urea, plus utility facilities. The ammonia plant and utility facilities are provided by Rekind and urea plant together with urea technology by Toyo.

CP Kelco announces CMC capacity expansion plans

December 12, 2012 — CP Kelco (Atlanta, Ga.; www.cpkelco.com) has announced plans to increase the carboxymethyl cellulose (CMC) capacity at its production facility in Äänekoski, Finland. CP Kelco will be expanding purified CMC capacity up to 25% at this facility over the next 12 to 18 months. The Äänekoski plant is already said to be the largest purified CMC manufacturing facility in the world.

MERGERS AND ACQUISITIONS

Clariant divests several businesses to SK Capital

January 2, 2013 — Clariant AG (Muttenz, Switzerland; www.clariant.com) has signed an agreement to divest its textile chemicals, paper specialties and emulsions businesses to SK Capital, a U.S.-based private investment firm with a focus on the specialty materials, chemicals and healthcare sectors. The divestment has been approved by the Boards of both companies. Subject to regulatory approvals, the transaction is expected to close by the end of the second quarter of 2013. The total consideration of the sale amounts to approximately CHF 502 million.

BASF to sell Meyco Equipment business to Atlas Copco

December 21, 2012 — BASF SE has signed a contract with Atlas Copco to sell its Meyco Equipment business, which provides concrete spraying machines to the mining industries. The machinery manufacturer, which is based in Stockholm, Sweden, will continue operations at the production site of Meyco Equipment in Winterthur, Switzerland. Both parties have agreed to not disclose financial details of the transaction.

AkzoNobel to divest its North American Decorative Paints business

December 14, 2012 — AkzoNobel (Amsterdam, The Netherlands; www.akzonobel.com) has announced the divestment of its North American Decorative Paints business to PPG Industries, Inc. (PPG; Pittsburgh, Pa.; www.ppg.com), for the value of $1.05 billion. In 2011, the North American Decorative Paints business had revenues of $1.5 billion.

Altana acquires the business of the wax additive manufacturer ChemCor

December 7, 2012 — The specialty chemicals group Altana (Wesel, Germany; www.altana.com) has signed a contract to acquire the business of Chemical Corporation of America Inc. (ChemCor), a U.S. manufacturer of wax additives. Altana will acquire the production site in Chester, N.Y. The business will be integrated into BYK USA Inc., which is based in Wallingford, Conn. and belongs to the Altana Additives & Instruments div. ■

Dorothy Lozowski

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

February 2013; VOL. 120; NO. 2

FOR MORE ECONOMIC INDICATORS, SEE NEXT PAGE

2010 — 2011 — 2012

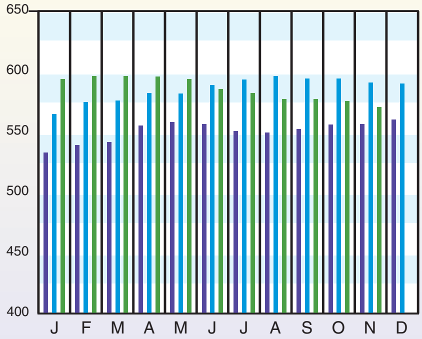
DOWNLOAD THE *CEPCI* TWO WEEKS SOONER AT WWW.CHE.COM/PCI

CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957-59 = 100)	Nov.'12 Prelim.	Oct.'12 Final	Nov.'11 Final
***CE* Index**	570.8	575.4	590.8
Equipment	691.7	698.2	721.0
Heat exchangers & tanks	634.0	638.5	686.7
Process machinery	656.7	658.4	674.1
Pipe, valves & fittings	890.4	899.4	899.3
Process instruments	420.9	424.4	428.0
Pumps & compressors	895.8	929.0	910.4
Electrical equipment	511.2	512.2	510.6
Structural supports & misc	726.0	734.2	767.5
Construction labor	322.2	323.7	326.6
Buildings	524.3	525.4	519.0
Engineering & supervision	328.2	327.9	330.4

Annual Index:

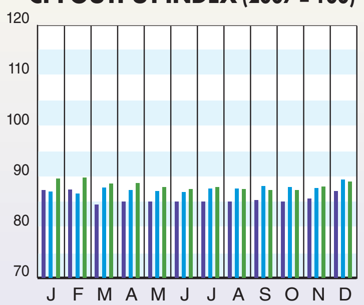
2004 = 444.2
2005 = 468.2
2006 = 499.6
2007 = 525.4
2008 = 575.4
2009 = 521.9
2010 = 550.8
2011 = 585.7



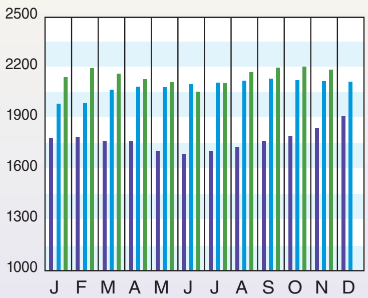
CURRENT BUSINESS INDICATORS

	LATEST			PREVIOUS						YEAR AGO		
CPI output index (2007 = 100)	Dec.'12	=	89.0	Nov.'12	=	88.0	Oct.'12	=	87.3	Dec.'11	=	89.412
CPI value of output, $ billions	Nov.'12	=	2,191.4	Oct.'12	=	2,208.7	Sep.'12	=	2,203.2	Nov.'11	=	2,140.28
CPI operating rate, %	Dec.'12	=	76.7	Nov.'12	=	75.9	Oct.'12	=	75.4	Dec.'11	=	77.222
Producer prices, industrial chemicals (1982 = 100)	Dec.'12	=	300.2	Nov.'12	=	297.3	Oct.'12	=	299.7	Dec.'11	=	304.4
Industrial Production in Manufacturing (2007=100)	Dec.'12	=	95.1	Nov.'12	=	94.3	Oct.'12	=	93.1	Dec.'11	=	92.8613
Hourly earnings index, chemical & allied products (1992 = 100)	Dec.'12	=	157.5	Nov.'12	=	157.3	Oct.'12	=	157.3	Dec.'11	=	158.521
Productivity index, chemicals & allied products (1992 = 100)	Dec.'12	=	104.9	Nov.'12	=	104.6	Oct.'12	=	103.2	Dec.'11	=	108.415

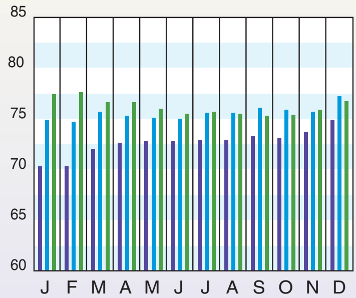
CPI OUTPUT INDEX (2007 = 100)



CPI OUTPUT VALUE ($ BILLIONS)



CPI OPERATING RATE (%)



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

CURRENT TRENDS

Preliminary data from the *CE* Plant Cost Index (CEPCI; top) for November 2012 (the most recent available) indicate that capital equipment prices dropped 0.79% from October to November. The current-year plant cost index is 3.4% lower than it was in November of the previous year (2011). Within the CEPCI, the preliminary November numbers indicate that all equipment-class subgroups, as well as construction labor and buildings, are down from the October values, while the engineering and supervision index rose slightly. Meanwhile, the Current Business Indicators from IHS Global Insight (middle), show a 1.1% increase in the latest CPI output index from November to December 2012. ■

DO YOU HAVE WHAT IT TAKES?

2013 *Chemical Engineering* & ChemInnovations Awards

WINNERS WILL BE RECOGNIZED IN CHEMICAL ENGINEERING MAGAZINE

Nominations are now being accepted for the 2013 *Chemical Engineering* and ChemInnovations Awards. Winners will be announced during the 2013 *Chemical Engineering* & ChemInnovations Awards Banquet on **Tuesday, September 24, 2013** at the **Moody Gardens Hotel** and **Convention Center**.

SUBMISSION DEADLINE - JULY 22, 2013

Join the list of prestigious companies to have previously won: BASF, Braskem S.A, Formox AB, LyondellBasell, JR Johanson, Inc. The Dow Chemical Company, UOP LLC, A Honeywell Company

For additional information and/or to submit a nomination for consideration visit **www.cpievent.com/award_nomination**.

COMPANY AWARDS

Unit Operations Awards

Innovative Energy Use Award

Best Process Plant Facility Improvement Award

The Safety Investment Award

Community Service Award

Early Adopter Award

Process Control and Automation Award

INDIVIDUAL AWARDS

"Jack of all trades" Award

Next Generation Award (fewer than 15 year's experience)

Plant Manager of the Year

PRESENTED BY:

CHEMICAL ENGINEERING

CHEM INNOVATIONS CONFERENCE & EXPO