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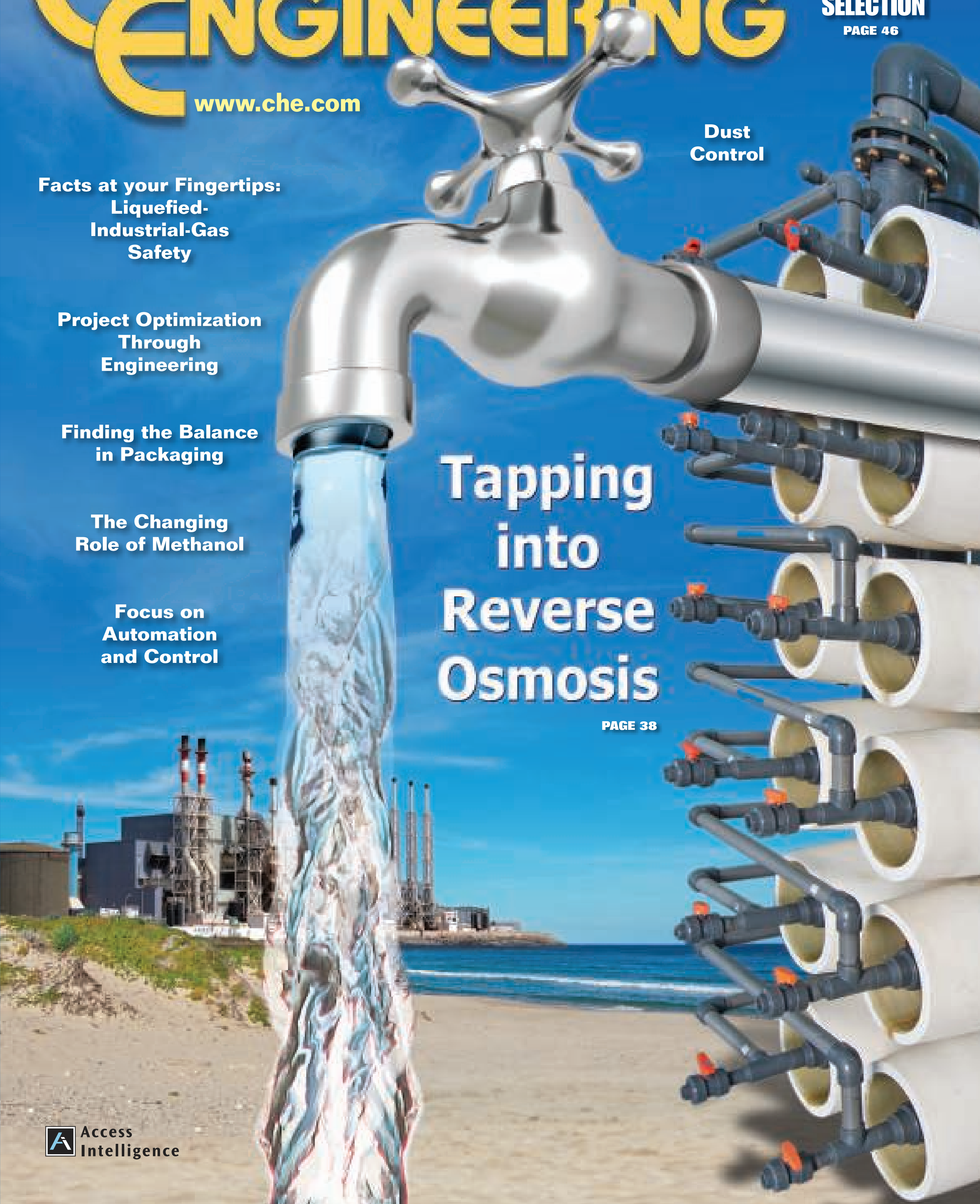

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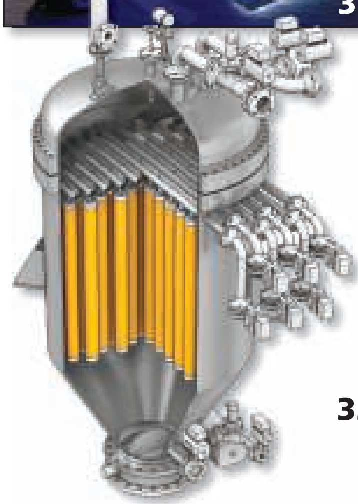

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Editor's Page

Finding job satisfaction

What do you look for in a job? It is an interesting question, and one that has received more attention in recent years as employers, who are struggling to find and attain the "right" person for a particular job, realize that job expectations are changing. This struggle is perhaps most prominent in finding highly skilled employees, such as those needed in the chemical process industries (CPI). And employees are more likely to change jobs more frequently now than in the past, as they look for a better fit.

In a recent webinar presentation*, Keith Wolf, managing director of Murray Resources (Houston; www. murrayresources.com) stated that 85% of employees are "open" to new opportunities, meaning that they are either looking for another position or are open to talking to a recruiter about one. A rather staggering figure that he quoted is that the U.S. Dept. of Labor Statistics estimates that today's learner will have 10–14 jobs by the age of 38. Wolf explained that it is not clear what factors are included in this number, such as different job titles at the same company, but even if the estimate is off by a large factor, it still points to a trend that employees are changing jobs frequently. Wolf said that some young employees consider staying at a position for two years as a long time, and do not consider it "job-hopping" to change that often.

So what are employees looking for in a job? The following are the main motivators for top talent, in order of importance, as presented by Murray Resources' Wolf: 1) quality of life; 2) potential for success; 3) impact of work; 4) opportunities for career development; 5) geography; and 6) money.

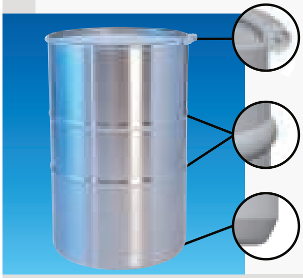
Understanding what motivates employees is also being studied in Europe, where competition for talented technical and scientific personnel is also a concern. Results of a multi-sector study carried out by the research institute Forsa on behalf of the specialty chemicals group Altana (Wesel, Germany; www.altana.com) were recently released. The findings, like those of the Houston-based group, placed factors other than financial rewards at the top of the list.

The "Industry Innovation Index" study by Forsa on behalf of the Altana group was conducted in late 2013, and included 500 interviews with representatives of industrial companies with 250 or more employees. Half of the interviewees were board members, managing directors and department heads, and the other half were entry-level employees with 2–5 years of experience. The factors considered to be very important in selecting an employer are the following (the percentage of respondents who considered them to be very important is given in parentheses): cooperative working atmosphere (87%); accountability and scope for action (66%); opportunities for promotion (56%); success of the company (47%); company image (34%); future viability of the industry (34%); salary (28%); and culture of innovation (28%).

What each individual seeks in his or her job may, of course, differ greatly from the findings mentioned above. If you would like to share what is important to you in a job, we would like to hear from you, either in a letter to the editor (letters@che.com) or as a comment in our LinkedIn discussion (http://linkd.in/1iuTE2I). ■

Dorothy Lozowski, Editor in Chief

* The webinar, "How to Attract and Retain Top Talent", can be accessed on-demand at http://www.che.com/toptalent/



Letters

May Technology Profile

I would like to ask the following questions and offer the following comments regarding the May 2014 Technology Profile (Ethanol from the Direct Gasification of Biomass, p. 43).

- What is the overall yield of ethanol (in gallons per pound of dry biomass), as well as the total cost of the process (in dollars per gallon of ethanol), and its energy efficiency (energy content of ethanol/energy content of biomass)?
- How do the economics compare with biochemical production of ethanol?
- The first step indicated in the process (biomass drying) may be unnecessary because biomass is gasified with steam. The ability to process wet biomass directly is an advantage of gasification over some other thermochemical methods.
- Instead of venting CO_2 to the atmosphere, it could be partially recycled to the gasifier or concentrated and sold as a byproduct. Using CO_2 to make urea fertilizer to grow the biomass feedstock is an indirect way of recycling CO_2.
- A $CoCu/SiO_2$ catalyst (Su, J. et al., *AIChE J.*, 60(5), 1,797–1,809, May 2014. http://onlinelibrary.wiley.com/doi/10.1002/aic.14354/abstract) could be an alternative to the MoS_2-based catalyst.
- Using electricity from the grid might be more economical than generating it internally in the plant.
- If the ethanol is going to be blended with gasoline, it need not be separated from the other alcohols; a mixed-alcohol stream containing ethanol would be better and less costly.
- Finally, you may wish to compile all Technology Profiles into a book for easy access.

Thank you very much.

Sorab R. Vatcha, consultant
Mountain View, Calif.

Intratec responds:

In response to Mr. Vatcha's first questions, Intratec, as the authors of Technology Profile columns, relates the following information: The ethanol product yield is 65 gal/dry short ton of feedstock. Operating costs are about $0.65 per gal of ethanol. The energy efficiency (energy content of ethanol/energy content of feedstock) corresponds to 0.40 (wet basis).

As to the remaining questions, we welcome Mr. Vatcha, and all other *Chemical Engineering* readers, to visit our website at www.intratec.us/ask-for-new-publications.

Editor's note: In response to Vatcha's final question, *Chemical Engineering* does offer a compilation of the Technology Profile columns. The 2013 version can be found at http://store.che.com/product/book/237.html, and the 2014 version will be available at the end of the year. To find it, visit website: http://store.che.com.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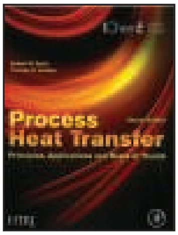
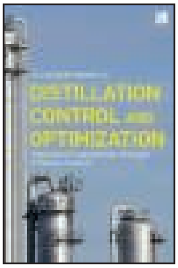
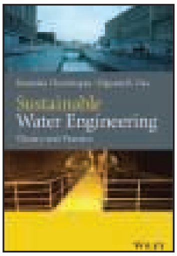


Process Heat Transfer: Principles, Applications and Rules of Thumb. 2nd ed. By Robert Serth and Thomas Lestina. Elsevier Inc., 225 Wyman Street, Waltham, MA 02144. Web: elsevier.com. 2014. 632 pages. $120.00.

Engineering Plastics. By T.R. Crompton. Smithers Rapra Publishing, Shawbury, Shrewsbury, Shropshire, SY4 4NR, U.K. Web: smithersrapra.com. 2014. 264 pages. $205.00.



Distillation Control and Optimization: Operation Fundamentals Through Software Control. By Alessandro Brambilla. McGraw-Hill Professional, 2 Penn Plaza, 9th floor, New York, NY 10121. Web: mhprofessional.com. 2014. 416 pages. $90.00.

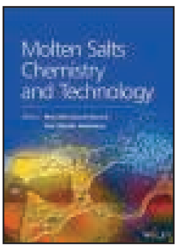


Sustainable Water Engineering: Theory and Practice. By Ramesha Chandrappa and Diganta Das. Wiley & Sons Co., 111 River Street, Hoboken, NJ 07030. Web: wiley.com. 2014. 430 pages. $160.00.

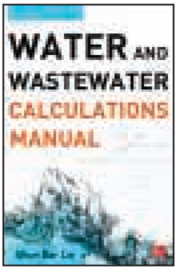
Process Technology Equipment and Technology. 4th ed. By Charles Thomas, Cengage Learning, 10650 Toebben Drive, Independence, KY 41051. Web: cengage.com. 2014. 544 pages. $150.00.

Advances in Biorefineries: Biomass and Waste Supply Chain Exploitation. Edited by Keith Waldron. Woodhead Publishing, Elsevier Inc., 225 Wyman Street, Waltham, MA 02144. Web: elsevier.com. 2014. 936 pages. $365.00.

Sintering: From Empirical Observations to Scientific Principles. By Randall M. German. Butterworth-Heinemann, Elsevier Inc., 225 Wyman Street, Waltham, MA 02144. Web: elsevier.com. 2014. 544 pages. $130.00.

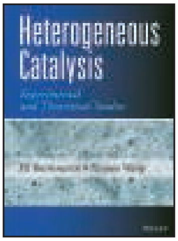


Molten Salts Chemistry and Technology. By Marcelle Gaune-Escard and Geir Martin Haarberg. Wiley & Sons Co., 111 River Street, Hoboken, NJ 07030. Web: wiley.com. 2014. 632 pages. $365.00.

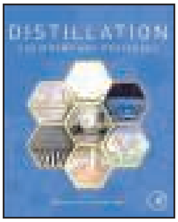


Water and Wastewater Calculations Manual. 3rd ed. By Shun Lin. McGraw-Hill Professional, 2 Penn Plaza, 9th floor, New York, NY 10121. Web: mhprofessional.com. 2014. 944 pages. $125.00.

Water Reclamation and Sustainability. By Satinder Ahuja. Elsevier Inc., 225 Wyman Street, Waltham, MA 02144. Web: elsevier.com. 2014. 496 pages. $230.00.

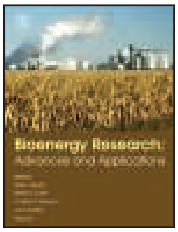


Heterogeneous Catalysis: Experimental and Theoretical Studies. By Eli Ruckenstein and Haiyou Wang. Wiley & Sons Co., 111 River Street, Hoboken, NJ 07030. Web: wiley.com. 2014. 760 pages. $195.00.

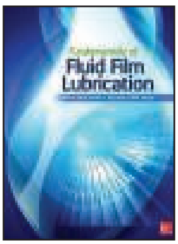


Expanders for Chemical Process: Design, Applications and Troubleshooting. By Murari Singh, Michael Drosjack and David Linden. McGraw-Hill Professional, 2 Penn Plaza, 9th floor, New York, NY 10121. Web: mhprofessional.com. 2014. 512 pages. $125.00.

Distillation: Equipment and Processes. Edited by Andrzej Gorak and Zarko Olujic. Academic Press, Elsevier Inc., 225 Wyman Street, Waltham, MA 02144. Web: elsevier.com. 2014. 420 pages. $195.00.



Bioenergy Research: Advances and Applications. By Vijai Gupta, Maria Tuohy, Christian Kubicek, Jack Saddler and Feng Xu. Elsevier Inc., 225 Wyman Street, Waltham, MA 02144. Web: elsevier.com. 500 pages. $179.95.



Fundamentals of Fluid Film Lubrication. By Mihir K. Ghosh, Bankim Majumdar and Mihir Saranji. McGraw-Hill Professional, 2 Penn Plaza, 9th floor, New York, NY 10121. Web: mhprofessional.com. 2014. 496 pages. $150.00.

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Chementator

Edited by Gerald Ondrey July 2014

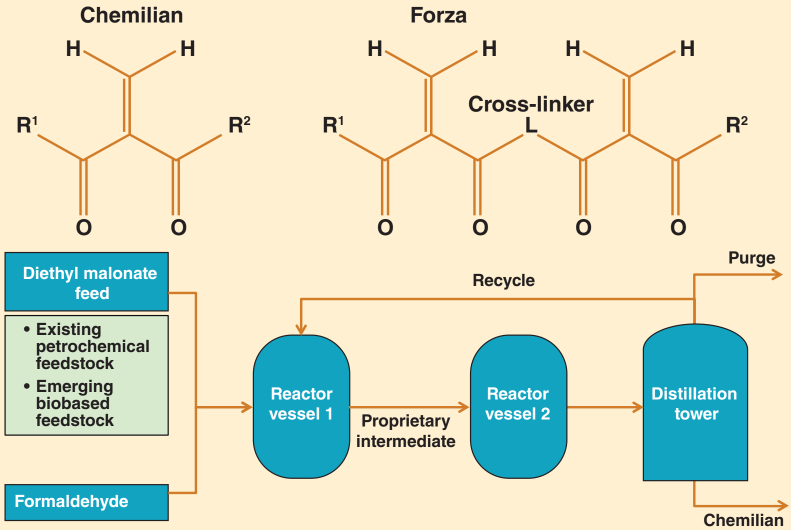
Platform for reactive monomers enables short cure times for coatings

The potential usefulness of 1,1-di-substituted alkenes for making performance polymers has been recognized for some time, but commercialization has been elusive because of the reactive nature of the monomers. Startup company Sirrus Inc. (Loveland, Ohio; www.sirruschemistry.com) has developed technology to stabilize monomers in this chemical class, as well as the intermediates that precede them, enabling their use in coatings and other applications.

Coating products resulting from the anionic polymerization of 1,1-di-substituted alkenes have several significant advantages, explains Sirrus CEO Jeff Uhrig, including rapid curing times at ambient temperatures, which can dramatically reduce energy consumption. And by tailoring the chemical structure of the monomers (diagram, top), we are able to generate products with a range of performance properties using a single chemistry platform, Uhrig says.

The Sirrus process (flowsheet) starts with the diethyl ester of malonic acid, which reacts with formaldehyde under controlled conditions to yield a proprietary intermediate species. The intermediate then reacts with a specially designed heterogeneous catalyst system to make the monomer. A critical component of the process is the set of compounds added to the reaction mixture to stabilize the monomer product, including species that prevent premature polymerization of the monomer by both the anionic- and free-radical-polymerization routes.

In addition to altering the chemical groups on the alkene, Sirrus also tailors the stabilization package to the demands of a particular application, Uhrig says. The company now produces two related alkene monomers — one with a cross-linker (known as Forza) and one without (known as Chemilian) — that can be combined to achieve the desired properties of hardness, optical clarity, temperature resistance and others.



Uhrig says the company currently manufactures 35–40 kg/wk of monomer for testing by potential users. Sirrus is in talks with multiple original equipment manufacturers (OEMs) in the automotive industry, as well as with chemical suppliers, to form manufacturing partnerships surrounding the production of monomer for various coating applications. In the future, Sirrus may establish its own manufacturing facility and explore the use of the monomers in a much wider range of applications.

Oil-water separation

A complex formed by combining maleic anhydride copolymers with a cationic fluorosurfactant can separate oil from water when coated on a wire mesh. Researchers at Durham University (U.K.; durham.ac.uk) devised a method of preparing the complex in a single step. This may render it more readily produced at industrial scales compared to previous efforts, the researchers say. In the complex, fluorinated alkyl chains orient toward the air-solid interface to form a low-surface-energy film. This orientation localizes

(*Continues on p. 16*)

A new route to a cellulose-based bioplastic

NEC Corp. (Tokyo, Japan; www.nec.com) has developed a two-stage, heterogeneous synthesis for making a high-functionality bioplastic (70 wt.% plant content) from non-edible plant cellulose. The new bioplastic is said to have excellent thermo-plasticity (275 MFR), heat resistance (140°C glass transition temperature) and water resistance, properties that make it suitable for durable products, such as electronic devices. The company plans to mass-produce the bioplastic during 2016.

To make the biopolymer, swollen gel-like cellulose materials are first reacted with modified cardanol (long-chain components derived from the agricultural byproduct, cashew-nut shells) and acetic acid (short-chain component) at temperature of 100°C or less to make a resin. The resin can be easily recovered by solid-liquid separation methods, such as precipitation and filtration. Unlike conventional homogeneous processes, NEC's process does not require a solvent for recovering the product resin. As a result, the overall process uses 90% less solvent than conventional methods, says the company. Energy requirements are said to be one tenth those needed by alternative routes.

Note: For more information, circle the 3-digit number on p. 68, or use the website designation.

An improved PHA-bioplastic process is scaled up

A less expensive process for producing biodegradeable polyhydroxyalkanoate (PHA) plastics from renewable feedstocks is being scaled up by a factor of six, resulting in a 30,000–60,000-lb/mo pilot facility. The improved PHA process — developed by Meredian Inc. (Bainbridge, Ga.; www.meredianpha.com) — stems from a patent portfolio initially established by Proctor and Gamble. The microbial fermentation process transforms natural oils into branched PHA, with a variety of alkyl groups on its side chains.

Meredian has introduced a set of innovations that confer several advantages over petroleum-derived PHA. "We developed a non-solvent filtration step that lowers production cost and results in a higher-purity product, as well as a microbial strain that increases product yield," comments Paul Pereira, Meredian's board chairman. The Meredian PHA process currently has costs within 15 to 20% of that for petroleum-derived PHA, but the company says it will be able to lower the cost to well below that as it scales up over the next four years.

Meredian also developed a proprietary technique known as reactive extrusion, which allows the introduction of ingredients to newly synthesized PHA in order to customize its properties, including stiffness and pliability.

The Meredian process begins by crushing seeds of the canola plant to obtain the feedstock oil. Fatty acids from the oil are fermented by microorganisms that store the product PHA inside their cells. The cells are lysed to harvest the PHA, and a water-based filtration process isolates PHA powder. The high-purity powder is then fed into the reactive extruder, where specific ingredients are added depending on the desired properties of the resulting bioplastic resin pellets.

PHA from Meredian's currently operating pilot plant has been approved for food contact applications by the U.S. Food and Drug Admin. (FDA). Pereira says Meredian will market PHA as a replacement for traditional petroleum-based polymers in applications such as foam cups and films for food packaging and bags.

Meredian is completing the buildout of the main production facility with a capacity of 60 million lb/yr in Bainbridge, Ga., where it recently harvested 1,000 acres of canola seed and will replant canola on 20,000 acres of land. The company's strategic model is to incubate clients to market entry and then license its technology to other manufacturers for market growth.

This on-purpose butadiene process takes a step closer to commercialization

Last month, The Linde Group (Pullach, Germany; www.linde.com) and BASF SE (Ludwigshafen, Germany; www.basf.com) announced plans to cooperate in developing and licensing processes for the on-purpose production of linear butenes and butadiene. BASF has developed process technology and catalysts as well as the extraction technologies, while Linde is providing its expertise for the integration, optimization and commercialization of the process.

Butadiene is a monomer used for the production of polymers, paper coating and synthetic rubber mainly for tire production. Butenes are building blocks that are used in the chemical and petroleum-refining sectors. Currently, the industry relies mainly on butadiene as a co-product from naphtha-cracking to ethylene. The shift to lighter cracker feedstock (see "Shale Gas Ushers in Ethylene Feed Shifts," *Chem. Eng.*, October 2012, pp. 17–19) results in reduced volumes of co-products (C3 and C4 hydrocarbons). Therefore the on-purpose production of higher olefins is gaining more and more importance.

The new process will deliver an on-purpose route from butane to butadiene via butenes. For the synthesis of butenes from butane, BASF developed a novel monolithic catalyst that is said to utilize the precious-metal component much more efficiently than conventional technology, while achieving a high yield of butenes. Linear butenes are oxydehydrogenated into butadiene using a mixed metal-oxide catalyst, which has a high activity and selectivity, says BASF. Butadiene is extracted from the C4 stream using a butadiene-selective solvent, and then purified by distillation. The BASF extraction technology has been proven for butadiene, and will be used for the purification in both process steps.

"The new BASF technology is currently being developed by mini-plant (kilogram scale) and pilot-plant (500 kg/h) operation in Ludwigshafen," says Heinrich-Josef Blankertz, senior vice president Global Technology, of BASF's Petrochemicals division. "We are optimistic that we can offer a new best-in-class technology for the manufacturing of on-purpose butadiene to help producers meet the increasing global demand."

A polymer for longer-lasting membranes

While super glassy polymers are initially very porous and ultra-permeable — a property that makes them suitable as gas-separation membranes — they quickly pack into a denser phase becoming less porous and permeable. Now, new materials that prevent such aging of these plastics have been developed by researchers from CSIRO Division of Materials Science and Engineering (Melbourne; www.csiro.au), Monash University (Melbourne; www.monash.edu.au), Australian National University (Canberra, all Australia; www.anu.edu.au), and the University of Colorado (Boulder; www.colorado.edu). The researchers believe they have solved the aging problem by adding an ultraporous material that maintains the low-density, porous, initial stage of the polymers through the absorption of a portion of the polymer chains within its pores, thereby holding the chains in their open position. They believe this is the first time that aging in super glassy polymers has been inhibited while maintaining enhanced CO_2 permeability for one year and improving CO_2/N_2 selectivity.

The researchers demonstrated that the addition of a very specific microparticle-porous aromatic framework (PAF) forms an interwoven nanocomposite with super glassy polymers, which freezes the structure and thus stops the aging process while increasing the gas permeability and selectivity. This was achieved by casting super-glassy polymer/PAF membranes with slow solvent evaporation. The addition of PAF into super glassy polymers increases the CO_2 permeability, from 25% in poly(trimethylsilylpropyne) to 320% in polymers with intrinsic microporosity (PIM-1). These results can be explained by the increased pore fraction that PAF introduces to the system.

The researchers say their approach can lead to dramatic enhancement across the entire family of rigid, microporous organic polymers, making these materials once again attractive for long-term industrial use, especially for PIM-1 membranes, because the CO_2/N_2 selectivity is increased without the typical reduction of CO_2 permeability.

(*Continued from p. 11*)

hydrophilic portions of the polymer closer to the surface via electrostatic interactions, the research team explains in a recent paper in *Applied Materials and Interfaces*. The resulting complex has an oleophobic outer surface, with a hydrophilic subsurface, and the combination can allow water molecules to penetrate through defects in the fluorinated outer layer, while keeping larger oil molecules on the surface. When coated on stainless-steel mesh, the complex is capable of separating an oil-water mixture by allowing the water to pass, while oil runs off the sloped upper surface, the researchers say.

Renewable degreaser

Elevance Renewable Sciences, Inc. (Woodridge, Ill.; www.elevance.com) recently launched a bio-based solvent for industrial degreasing applications that is made from plant oils, such as palm, soy or canola. Elevance senior vice president Andy Corr says the renewable solvent outperforms conventional solvents, as well as other bio-based solvents, in terms of dissolving efficiency and speed. Known as Elevance Clean 1200, the product dissolves industrial-grade greases, such as lithium and molybdenum disulfide complex greases, as well as paraffin waxes, automotive lubricants and others, in heavy manufacturing, food processing and manufacturing MRO (maintenance, repair and overhaul) applications, Corr says. Elevance Clean 1200 is designed for neutral-pH applications, allowing users to work with less corrosive formulations and reduce hazardous handling environments. The solvent complements an earlier product introduced by Stepan Co. in a joint development collaboration — the bio-based surfactant Steposol MET-10U (*Chem. Eng.*; May 2014, p. 11).

New polymer is said to be first-ever recyclable thermoset

A new thermoset polymer has been discovered by researchers at IBM Research Almaden (San Jose, Calif.; www.research.ibm.com). The new material, polyhexahydrotriazine (PHT), has a very high Young's Modulus (up to 14 GPa, compared with a Young's Modulus of 4 GPa for typical polyimide thermosets), along with many other characteristics that make it a suitable thermosetting material. However, unlike traditional thermosets, PHT is recyclable — when placed in a low-pH solution of sulfuric acid, it depolymerizes back to aniline-based monomers that can be re-polymerized. The reaction to form PHT is also simple, and uses readily available and relatively inexpensive raw materials. The team from IBM remains optimistic that the process could be scaled up to industrial levels.

The formation of PHT consists of a polycondensation reaction between an aniline monomer (in this case, 4,4,'-oxydianiline) and paraformaldehyde. After a cyclization step, the resulting structure is a six-membered ring with three nitrogen-containing units. These nitrogen components form the "arms" of the monomers, providing three points for polymerization on each ring. The researchers believe that the arrangement of the nitrogen-containing units within the polymer structure contribute to its impressive strength.

The applications for PHT include typical thermosetting uses, such as in composites and electronics, but its recyclability and strength greatly expand its potential. While still very early in the discovery phase, there has been much positive commercial interest in PHT thermosets, although no official announcements have been made. The next steps in the research will be to examine the fundamental chemistry behind PHT and the conditions for its formation process, as well as investigating new potential applications.

Waste-to-fuel

Indian researchers have developed a relatively low-temperature process for transforming plastic waste, including low-density polyethylene into a liquid fuel. The researchers are chemist Achyut Kumar Panda of Centurion University of Technology and Management (Bhubaneswar, Orissa; www.cutm.ac.in) and chemical engineer Raghubansh Kumar Singh of the National Institute of Technology (Rourkela, state of Orissa; www.nitrkl.ac.in). They used a process of thermo-catalytic degradation, heating plastic waste to between 400 and 500°C in a batch reactor at atmospheric pressure, over a kaolin catalyst. The process releases large quantities of much smaller components, mainly paraffins and olefins (10 to 16 carbon atoms long), which are chemically similar to conventional petrochemical fuels.

The kaolin acts as a catalyst by providing a large reactive surface to which the polymer

(*Continues on p. 20*)

This fatty-acid conversion process results in synthetic lubricant base oils

Biosynthetic Technologies (Irvine, Calif.; www.biosynthetic.com) has developed a continuous-flow process to convert any animal- or plant-based fatty acids with high oleic-acid content into synthetic esters that can be used in formulations for motor oils and industrial lubricants. These biosynthetic esters have extremely high oxidative stability, good hydrolytic stability and very low evaporative loss, the company says. Additionally, the oils are biodegradable, non-toxic and not bio-accumulative. When included in motor-oil formulations, the biosynthetic ester products have been shown to be effective at preventing deposits of varnish and sludge from accumulating on engine surfaces, lengthening engine life.

Biosynthetic Technologies' process has its origins in research by the U.S. Department of Agriculture that focused on linking long-chain carboxylic acids to form esters. Biosynthetic Technologies licensed the original technology and added its own intellectual property as it commercialized the process, says Allen Barbieri, the company's CEO.

After the fatty-acid starting material undergoes an acid-catalyzed oligomerization reaction, the product is distilled and then undergoes an esterification reaction to generate the synthetic ester product, known as an estolide. The manufacturing process is designed to minimize waste and utilize 100% of the feedstock with no byproducts, says Barbieri.

"The biosynthetic esters are polar compounds, unlike many synthetic lubricant basestocks, such as polyalphaolefins," explains Barbieri, and "as such, they are better at solubilizing oil sludge and preventing it from depositing on engine surfaces."

In a field trial conducted by Infineum International Ltd. (Abingdon, U.K.; www.infineum.com; a joint venture of ExxonMobil and Shell) on a fleet of Las Vegas taxicabs, cars using motor-oil formulations containing synthetic estolide from Biosynthetic Technologies showed considerably cleaner internal engine surfaces after 150,000 miles, than those using conventional motor oils.

Barbieri says that partner Albemarle Corp. (Baton Rouge, La.; www.albemarle.com) has built and is operating a demonstration plant to validate the continuous-flow manufacturing process for estolides, and is in the detailed engineering stages for a commercial-scale facility. Construction will begin in late 2014. In addition to being an alternative to Group IV and V lubricant-base oils, Biosynthetic Technologies' bio-based synthetic esters can be used in formulating other products, such as hydraulic fluids, industrial greases and personal-care products.

This inexpensive bioplastic takes the heat

New bio-based polyimides (PIs) that withstand temperatures up to 390°C — the highest ever reported for a bioplastic — have been developed by Tatsuo Kaneko at the Japan Advanced Institute of Science and Technology (JAIST, Nomi City; www.jaist.ac.jp), in collaboration with Naoki Takaya at the University of Tsukuba. The bio-based PIs are made from aromatic diamines, which are photodimerized, cinnamon-related compounds derived from genetically-engineered *Escherichia coli*. The *E. coli* was able to produce natural, but rare chemicals, such as 4-amino cinnamic acid.

In addition to the high temperature resistance, bio-based PI films were shown to have a high tensile strength (750 MPa) and Young's modulus (10 GPa); "excellent" transparency (88% at 450 nm); and a high refractive index (1.60). These properties make the material suitable as alternatives to metals for lightweight automotive applications. The scientists estimate a production price for the bio-PI film (density of 1.2 g/cm^3) is around $30/kg, which is comparable to food packaging, and lower than tempered glass (density of 2.5 g/cm^3) used in automobiles. ■

(*Continued from p. 18*)

molecules can attach and be exposed to high temperatures that break them apart. The catalyst increases the yield of the condensable product while decreasing the reaction time. The highest yield of liquid fraction (79.5 wt.%) was achieved at 450°C with a 1-to-2 catalyst-to-plastics ratio.

Lignin-based PHA

Kaneka Corp. (Osaka; www.kaneka.co.jp), in collaboration with Riken (Wako City; both Japan; www.riken.jp), has demonstrated that the microorganism *Palstonia europha* H16 can synthesize polyhydroxyalkanoate (PHA) from components of lignin, such as 4-hydroxybenzoic acid (4-HBA) and several aromatic chemicals. In the case of 4-HBA, the accumulation of PHA in the microorganism was up to 63 wt.%, thus showing the potential for high productivity. The molecular weights of the products are rather low compared to HBA made from sugars or vegetable oils, but have properties that show potential for plastic-film products. Kaneka plans to apply its achievement to the production of materials while utilizing the lignin-containing waste from paper factories.

More efficient decanter

Alfa Laval AB (Lund, Sweden; www.alfalaval.com) recently introduced the Aldec G3 decanter centrifuge, a new generation of decanter centrifuge that can save as much as 40% on energy costs while increasing sludge-processing capacity by up to 10%, according to the company. Based on Alfa Laval's Slimline design, the Aldec G3 has a smaller conveyor diameter, which means there is room for more liquid in the "pond," and the pressure on the bowl wall can be higher, enabling a drier cake, says the company. Half of the energy savings is due to the Slimline configuration. The other half is due to the use of patented Power Plates, which captures some of discharge from the liquid leaving the unit, and redirects it in order to continue the bowl rotation. This reduces the discharge velocity, and thus, the overall power consumption. ❏

Newsfront

THE CHANGING ROLE OF METHANOL

As methanol becomes a more important building block, technology providers are improving catalysts and processes to make much more of it — economically

Since the turn of the new millennium, considerable changes have been taking place in the methanol sector. About ten years ago, methanol plans in the U.S. were being shuttered, while new ones, with much larger capacity — the so-called mega-methanol plants, with capacities of 5,000 metric tons per day (m.t./d), were being constructed in regions of the world with abundant, inexpensive natural gas (*Chem. Eng.*, May 2001, pp. 29–37). Today, the situation has changed dramatically, and continues to evolve.

On the one hand, the surge in coal-gasification projects in China — a country rich in coal but lean in natural gas — is causing an increased demand for all products made from synthesis gas (syngas), including methanol (*Chem. Eng.*, February 2011, pp. 16–20). On the other hand, natural gas prices have plummeted in the U.S. in the last few years, due to the "shale-gas boom," whereby unconventional natural gas sources and the associated natural gas liquids (NGLs) are rejuvenating the basic chemicals sector there. Shuttered methanol plants are being restarted and new plants are being built in North America — and even relocated there from other regions of the world — to take advantage of lower feedstock prices. As a result, the U.S. is projected to evolve from a methanol importer, to a methanol exporter by 2017, according to Marc Laughlin, director, Methanol & Acetone—Americas, at IHS (Houston; www.ihs.com).

Dynamic market

Methanol is a key building block for a large number of chemicals, such as formaldehyde, acetic acid, methyl *t*-butyl ether (MTBE), *t*-amyl methyl ether (TAME) and others (Figure 1). While modest but continued growth is expected for these traditional methanol derivatives, two methanol outlets are growing more rapidly: the use of methanol for gasoline blending and for making olefins — via either methanol-to-olefins (MTO) or methanol-to-propylene (MTP) processes. China is the major consuming country, having demand for every form of methanol derivative, says IHS's Laughlin.

Unlike the U.S., where the use of methanol in gasoline has not been approved by the U.S. Environmental Protection Agency (Washington, D.C.), fuel blends like M15, M45 and M85 are already a reality in China, and this trend is expected to increase further. China's domestic methanol demand is projected to grow from 30.1 million metric tons (m.t.) in 2013 to 51.8 million m.t. in 2018, with MTO/MTP's share increasing from 4% in 2013 to 18% in 2018, says Laughlin.

While the methanol used in these plants is made from syngas derived from coal gasification, investors are now looking to North America where the low cost of natural gas makes methane-reforming competitive again. In March, for example, OCI N.V. (Amsterdam, the Netherlands; www.ocinv.nl) announced that its wholly owned subsidiary, Natgasoline LLC, com-

Source: IHS

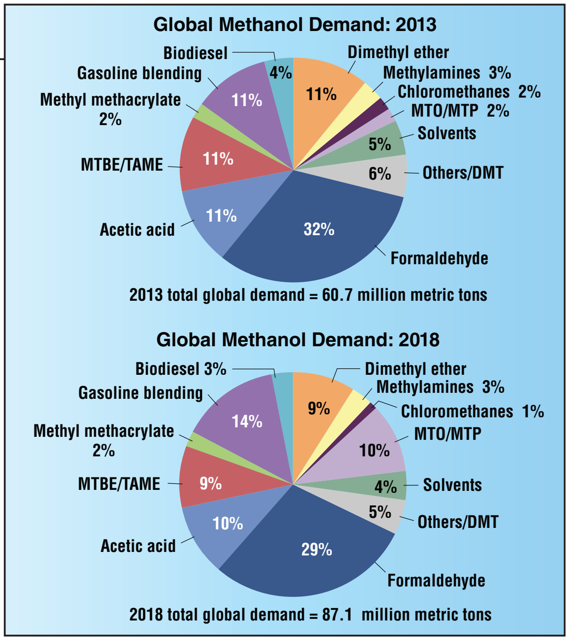


FIGURE 1. Methanol is a key building block for a number of important chemicals. And its role in the production of fuels and olefins is expected to grow

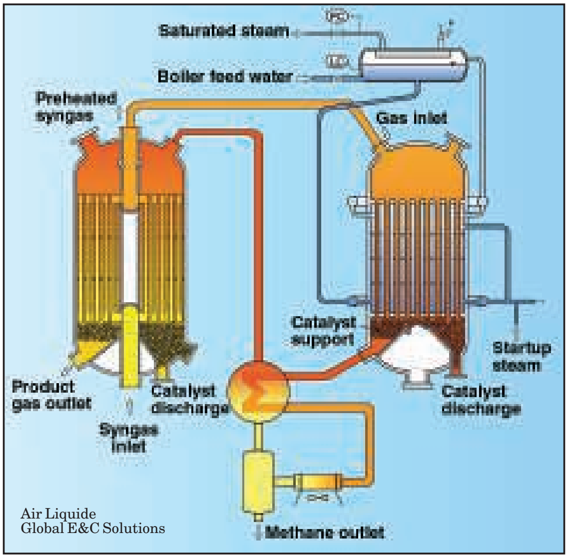


FIGURE 2. This methanol converter combines a steam-raising reactor (right) with a gas-cooled reactor (left)

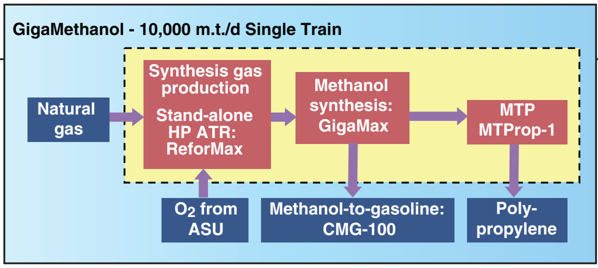
menced site preparation works for its new greenfield methanol plant in Beaumont, Tex. When it starts up in 2016, the plant will use the Lurgi MegaMethanol technology of Air Liquide Global E&C Solutions (Frankfurt, Germany; www.airliquide.com), processing natural gas into 5,000 m.t./d of methanol — the first methanol plant of this scale in the U.S., says OCI.

Making methanol

Methanol is made by reacting syngas (a mixture of CO, H_2 and CO_2) in a converter, such as shown in Figure 2. The methanol reaction is an exothermic, equilibrium controlled reaction, supported by a Cu/Zn catalyst. Heat removal is key in order to achieve optimum conversion levels as well as to protect the catalyst from accelerated aging by sintering of the metal crystallites, explains Ulf Herrlett, vice president, Technology at Air Liquide Global E&C Solutions. The "traditional" water-cooled reactor, a steam-raising multi-tubular reactor (previously developed for the fixed-bed Fischer-Tropsch process in the 1950s) fulfills the task of ensuring high reaction rates (with high heat release) coupled with excellent heat-removal properties by means of boiling water on the shell side (the catalyst is on the tube side). By applying this proprietary reactor type, temperature gradients of less than 3K can be achieved while achieving high per pass conversion, says Herrlett.

In order to further enhance the "traditional" design, continues Herrlett, two process improvements have been introduced: the gas cooled reactor (GCR) and interstage condensation. The GCR (Figure 2, left) can be considered as a "post reactor" in which the partially reacted gas leaving the water-cooled reactor (Figure 2, right) is further converted. The driving force for this reaction is the decreasing temperature in the GCR by means of heat exchange with fresh syngas. Due to a continuously decreasing reaction temperature, the equilibrium is shifted toward higher conversions, yielding overall higher per-pass conversions compared to a water-cooled reactor only, Herrlett says. "This process has been widely applied and is today the standard solution for world-scale capacity plants using our technology."

In order to further enhance the equilibrium conversion, the so-called interstage condensation is applied (Figure 2, bottom). Before entering the GCR, methanol is removed by condensation. As a result, the equilibrium is shifted toward higher methanol yields. This technology concept not only allows a reduction in the catalyst demand per ton of methanol produced, but also reduces the amount of pipe material required to implement the over-



Source: Clariant

FIGURE 3. Several companies have designs for doubling methanol capacities to 10,000 m.t./d in a single train, such as the GigaMethanol process shown here

all methanol synthesis loop, says Herrlett. "That leads to savings in both operating and capital costs."

New catalysts

For the synthesis of methanol from syngas, Clariant AG (Muttenz, Switzerland; www.clariant.com) — the strategic partner of Air Liquide — produces Megamax 800 catalyst, which can be used in all kinds of isothermal reactors, such as Air Liquide's Lurgi-type described above, as well as all other plant designs, such as adiabatic quench-type reactors. Megamax 800 is said to considerably increase the reliability, carbon efficiency and profitability of any type of methanol plant.

In addition, Clariant not only commercialized the first coal-to-propylene catalysts used in China, but also invested in local production of coal-to-methanol and other syngas catalysts. Furthermore, Clariant announced last month that it signed an agreement with Siemens Fuel Gasification Technology (Erlangen, Germany; www.siemens.com/energy) to cooperate in the commercialization of a new, jointly developed sour gas shift (SGS) technology for coal gasification.

The advanced SGS technology from Clariant and Siemens significantly decreases total capital cost for coal-to-chemical and other IGCC (integrated gasification combined cycle) applications through optimization and simplification of total plant concepts. Clariant's new ShiftMax 821 catalyst enables a simple, once-through process without further adjustment of the exit gas from the gasifier. The simplified layout uses smaller and fewer reactors, and requires no steam adjustment for temperature control. This combination reduces capital expenditure for the shift system by up to 20%, and optimizes operating costs with up to 30% lower catalyst volume, says the company.

Meanwhile, Haldor Topsøe A/S (Lyngby, Denmark; www.topsoe.com) is making inroads with its latest methanol-synthesis catalyst, MK-151 Fence. The basis for this new catalyst is the company's Fence technology, in which finely dispersed nano-sized particles of the active copper-metal crystals are separated from each other by a "picket fence" of metal-oxide crystals. This inorganic "fence" reduces the sintering of the copper during operation — a major deactivation mechanism in conventional catalysts — and thus extends the catalyst's activity and stability, says the company.

The new catalyst was introduced

a few years ago. Since then, at least nine industrial methanol converters have been charged with MK-151 Fence.

In 2009, Johnson Matthey (London; www.matthey.com) introduced Katalco Apico, its new reduced and stabilized methanol synthesis catalyst. The new catalyst — based on copper — is said to have a faster startup and a stable activity; it can achieve higher output over a longer time; it lasts longer without excessive pressure drop; and as a result of lower byproduct formation, makes more methanol out of the distillation process, says the company.

For any producer building a new plant, the size of the methanol synthesis reactors could be reduced — by up to 30% (in costs as well as weight) for some types of reactors — and higher plant efficiency is achieved, the company says.

The next wave: 10K

As the methanol market continues to evolve, companies are preparing for the next wave in methanol demand — fuels. Clariant and Air Liquide Global E&C Solutions have developed the next generation of methanol plant, the GigaMethanol process (Figure 3), which delivers, in a single train, 10,000 m.t./d of methanol.

In the past, syngas had been produced by steam reforming at pressures of around 17 bars, enabling plant sizes of 2,500 m.t./d, explains Air Liquide's Herrlett. With Lurgi MegaMethanol — which combines steam-reforming and O_2-blown autothermal reforming — syngas pressure was raised to about 30 bars, and capacities doubled to 5,000 m.t./d. Now, with GigaMethanol, in which there is no steam reformer, just an O_2-fed, high-pressure (HP) autothermal reactor (ATR), syngas pressures are delivered to the converter at pressures up to about 80 bars — the same pressure needed for the methanol synthesis. This feature eliminates the need for a compressor with associated investment and operating costs, he says.

The HP ATR process has been confirmed in a demonstration plant in Germany, and is now commercially available. Although the present demand for methanol does not necessarily justify such a large methanol plant, the situation could change dramatically if methanol becomes more important for making fuels.

Already ExxonMobil Research and Engineering Co. (EMRE; Fairfax, Va.; www.exxonmobil.com) is making strides to reintroduce its methanol-to-gasoline (MTG) technology, which was developed in the 1970s and first commercialized in 1986 when a 14,500 bbl/d facility started up in Motunui, New Zealand (*Chem. Eng.*, March 1986, p. 12E) — a plant that operated for 10 years. Currently, at least six MTG licenses have been announced by the company. Two of these are for coal-to-liquids projects in China for JAMA, Shanxi Province: a 2,500-bbl/d unit that started up in 2009, and a second, 25,000 bbl/d facility now under construction. The other licenses for MTG are in the U.S.

For example, in June 2012, Sundrop Fuels, Inc. (Longmont, Colo.; www.sundropfuels.com) finalized a licensing agreement to use EMRE's MTG technology for a commercial plant that will produce up to 50 million gal/yr of "renewable" gasoline. The plant, located near Alexandria, La., will generate syngas from biomass gasification, using the High-Temperature Winkler (HTW) process of ThyssenKrupp Industrial Solutions (Dortmund, Germany; www.thyssen-krupp-industrial-solutions.com).

Last month, G2X Energy, Inc. (Houston; www.g2xenergy.com), which has a multi-license, gas-to-gasoline agreement with EMRE, announced that its wholly owned subsidiary, Big Lake Fuels LLC, received the required air permits to construct and operate a natural-gas-to-gasoline facility in Lake Charles, La. The permits are the first to allow for the construction and operation of a commercial-scale plant to convert natural gas into liquid transportation fuels. The project will convert domestic natural gas into approximately 12,500 bbl/d of zero-sulfur gasoline or commercial-grade methanol, or both. Meanwhile, G2X's natural-gas-to-methanol plant in Pampa, Tex. is currently under construction.

Co-generation

Another potential growth area for methanol-technology providers is co-genereration plants, or so-called gas-based refineries. That means reforming natural gas and then integrating the syngas produced into multiple units for producing several different chemicals. It's becoming more attractive to investors if a project is not limited to a single chemical, says Per Juul Dahl, technology supervisor, process development, engineering production at Haldor Topsøe. Already for years we have made plants that primarily produce ammonia, with some methanol generated on the side. Now for the first time, the company is building its first integrated methanol and ammonia plant in Russia. The foundation stone was laid last May for the new plant, located in the Tula region of Russia for the petrochemical company, Shchekinoazot. When the facility starts up in 2017, it will produce 1,350 m.t./d of methanol and 415 m.t./d of NH_3, and will be the first commericial application of Topsøe's IMAP (integrated methanol and ammonia production) technology. ■

Gerald Ondrey

FINDING THE BALANCE IN PACKAGING

Packaging and distribution methods can provide both safe and sustainable transport

Dow

FIGURE 1. Dow's Elite Advanced Technology line of polyethylene resins allows film converters to deliver smarter, more advanced packaging solutions

Beckhoff Automation

FIGURE 2. The XFC PC-based control system allows packaging solutions to fill the correct amount, while reducing the amount of packaging materials used and reducing energy consumption across the supply chain

The word "sustainability" is used a lot, but for many businesses and industries it is increasingly becoming a challenge that must be taken seriously. As customers, large retailers and end-users continue to demand sustainable practices, packaging and products from their suppliers, chemical processors must start to change the way they package and deliver their goods, incorporating methods that encourage recycling, less waste and a cleaner carbon footprint.

Sustainable distribution can be a somewhat elusive and confusing term, but its definition is essentially twofold — first is selection of the proper packaging for the product, second is understanding how to use available materials or products in a way that is more sustainable and environmentally friendly.

The number one priority of any packaging is to ensure that the product gets to its destination — be that another business that will use the product to manufacture something else, the seller of the finished product or the end-consumer — in the same state that it left the processing facility or warehouse. "Packaging should prevent loss or damage to the product, which is a result of inadequate packaging," says Phillip Luijckx, marketing manager, Industrial & Consumer Packaging for Dow Performance Packaging (Houston; www.dow.com/packaging). "You don't need over packaging and you don't need under packaging. You want the right amount of the right material to be able to take that product through the supply chain without any damage or loss."

Second, the most appropriate material for the application should be selected, and it should be used in the proper way to ensure the least amount of environmental impact. "For example, a lot of people make the mistake of buying thinner gages of stretch film thinking that it will be lighter weight and create less waste and will, therefore, be the more sustainable choice," notes Luijckx. "However, they end up using double the amount, which creates the same amount of, if not more, waste, so they haven't understood how to use the material properly or they haven't selected the proper material. Being sustainable takes education to ensure that you're getting the most value from what you're buying and that it is truly a sustainable choice when it is used in the way that you plan to use it."

Victor Bell, president of Environmental Packaging International (Jamestown, R.I.; www.enviro-pac.com) says finding the appropriate balance between materials, product integrity and being kind to the environment is the real the challenge processors face when instituting sustainable packaging and distribution. "A good example of a poor balance is water bottles. People went crazy trying to make them thinner and thinner and ended up with bottles that punctured, broke and leaked easily, and they became more of a problem than not. Sustainability went overboard," Bell explains.

"What we try to explain is that there needs to be a balance and the initial concern should be for product integrity," says Bell. "A great example of a balance can be found in the food industry where a certain package may extend the life of a steak by three days. While this package may require an extra ounce of packaging, the amount of carbon footprint that's avoided by not throwing away that steak is much more significant than the amount required to create and dispose of that extra ounce of packaging. It's really more about optimized packaging than strictly environmentally friendly packaging."

And, Bell stresses the importance for chemical processors to be sure they have optimized packaging. "When chemical manufacturers consider sustainable packaging and distribution, it is especially crucial for them to first consider protecting the product. Leaks and spills can cause major problems if the product is a chemical, especially if it is hazardous," he notes. "But at the same time, the way the chemical industry transports its raw materials and ingredients often lends itself to being

Schütz

FIGURE 3. Schütz developed a collection system that takes care of free collection and reconditioning of empty IBCs

sustainable. They are recyclers of pails, pallets and drums, which not only safely transports their materials, but also keeps the packaging out of landfills."

Paul Burgess, a regulatory specialist with Labelmaster (Chicago, Ill.; www.labelmaster.com), agrees with Bell. "Chemical processors will always have to be concerned with the safe transport of their products above all else, so they have to select packaging and shipping options that meet the regulatory burden their chemicals fall under and then decide which of those possible products is the most sustainable choice."

Optimized design

Burgess adds that safe and sustainable choices are becoming more plentiful as the ISO 14001 environmental standard, which sets the criteria for an environmental management system, becomes more prevalent. "This standard makes it easier for chemical processors to engage in a sustainable pathway because fewer and fewer products are designed to be pitched out. Instead, more shipping and packaging products and materials offer the possibility of reuse or recycling."

As a result, optimized-for-the-environment products include everything from novel materials to packaging equipment to shipping containers.

Packaging materials. Materials manufacturers understand that there is a growing need for a variety of materials for a diverse set of applications, so new, more sustainable packaging materials are becoming widely available to suit the range of needs in industry.

Dow recently launched its Elite Advanced Technology line of polyethylene (PE) resins, which allow film converters to deliver smarter, more advanced packaging solutions (Figure 1).

The all-PE structure products in this line combine sealability, stiffness, high stretch, high-puncture resistance, impact strength and processability. These single-resin benefits can be applied to a variety of film, laminate, rotomolded and coated products.

As an example, for liquid, dry and frozen foods, Elite EPE resins help reduce package thickness by up to 25% without sacrificing toughness or machinability. On high-speed stretch film lines, the resins can run faster and thinner without compromising holding force. And for lamination films, packers can maintain stiffness and toughness while reducing pack weight. In these and other applications, including heavy-duty shipping sacks, the resins provide high performance and, because the whole structure is PE, it is easy to recycle for increased eco-friendliness.

Clariant AG (Muttenz, Switzerland; www.clariant.com) is working on more sustainable packaging solutions for products headed to consumers. The company's new generation Hydrocerol provides lighter plastic packaging. Hydrocerol chemical foaming agents reduce the amount of plastic needed to make packaging without compromising performance or aesthetics. Packaging weight can be reduced by up to 20%, while maintaining impact strength, high-quality surface finishing and compliance with requirements for direct food contact. Lighter weight packaging also reduces shipping costs and fuel consumption.

"The future direction of the packaging industry is steered by the need to protect contents in new, improved or less costly ways, and to make products and packages easier to use with less environmental impact," says Alessandra Funcia, head of market segment packaging at Clariant. "By developing innovation that combines shelf appeal or user convenience with performance advantages and improved sustainability, we can help converters and major brand owners to maintain both their profitability and competitive edge."

Packaging machinery. Increasing sustainability doesn't end with the packaging materials. It extends to packing machinery, as well. For example, Beckhoff Automation (Verl, Germany; www.beckhoff.com) touts its PC-based control system (Figure 2) as a way to implement packaging solutions that fill the correct amount, while reducing the amount of packaging materials used and reducing energy consumption across the supply chain. The company's XFC (extreme fast control) technology offers I/O response times of less than 100 µs to control the process with precision and repeat accuracy. The PC and EtherCAT-based control ensure synchronized processes and motion control sequences with shorter cycle times for more throughput. The technology's quick and precise response to printing marks makes it possible to save on packaging material, for example, by placing products more closely together in blister packs, which reduces the amount of sealing foil needed, as well as any waste.

The ability to precisely control the sealing temperature allows the use of thinner plastic films. Fast and accurate process control capabilities can minimize the wall thickness of polyethylene terephthalate (PET) bottles, as well as reduce the amount of paper and aluminum when producing containers.

Distribution. Sustainable distribution, also includes the way in which materials are transported from Point A to Point B. Sustainable distribution products are especially important for chemical processors who deliver bulk materials to other businesses who will then manufacture consumer or other products from these raw materials. For this group, the opportunity to reuse and recycle containers and components becomes critical to a sustainability program, and a plethora of products are available to this end.

For example, Cartonplast (Dietzenback, Germany; www.cartonplast.com) offers, to the container transport industry, plastic layer pads that can circulate in a closed logistics cycle. The pads, available on a rental basis, are reusable and 100% recyclable.

Similarly, Schütz (Selters, Germany; www.schuetz.net), developed its own collection system for its used Ecobulk containers. Once the goods have arrived at their destination, the empty containers are collected, as part of a global service the company offers, and returned to the factory where the IBC (intermediate bulk container) inner bottle is removed from the cage and shredded. The resulting regrind is recycled in several stages. The resulting high-density PE (HDPE) recyclate is used to manufacture plastic components, such as corner guards and pallets (Figure 3). Last year, the company won the "Greener Packaging Award 2013" in Brussels for this eco-friendly recycling and for the creation of its Ecobulk MX container with a new full plastic pallet (Figure 4).

Schutz

FIGURE 4. The Ecobulk MX with a new full-plastic pallet is shown here

As well as reusing recycled materials in products, Schutz IBCs are also sustainable products because they are space-saving logistical tools, according to the company. The container design, with a volume of 1,000 L, allows 25% more goods to be transported than with a conventional 220-L drum, using the same space requirement. This translates into fewer trucks and freight-train journeys, which saves fuel and cuts back on emissions.

Reuse is often as important as recycling when it comes to shipping containers, so Labelmaster offers Snapcrates reusable shipping crates (Figure 5). The heavy-duty crates can be reused 25 to 30 times, which saves on crate disposal costs and significantly reduces landfill waste. Between uses, the crates can be broken down, stored flat and reassembled in minutes without tools. Internationally rated for export, the crates ship securely. They are not currently UN-rated, but Burgess says they expect to receive certification in the future for use with hazardous materials.

Making the sustainable choice

With all the materials and options available, how does a processor know which material, package and shipping crate will provide the safest, most eco-friendly, but sensible product solution? There are several options.

Among them, Dow Pack Studios includes four locations around the world, which provide collaborative opportunities with Dow to create, fabricate and validate solutions for better packaging.

"Our customers can come to our labs and experiment with different technologies, materials and machines

Labelmaster

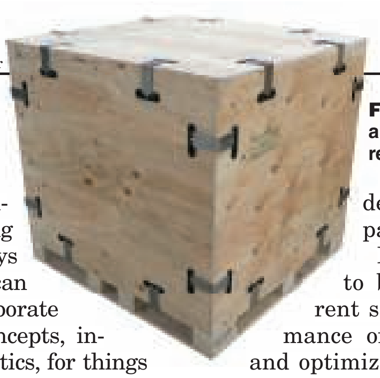


FIGURE 5. Snapcrates reusable shipping crates can be reused 25 to 30 times

and turn their concepts of packaging into reality," says Luijckx. "They can look at and collaborate on packaging concepts, including rigid plastics, for things like pails, shrink wrap, stretch hood films. And while we don't offer a recycling program, while the customer is here, we actively get them engaged in sustainability and promote those programs, as well as help them select the best packaging and qualify their choice using our different equipment and materials."

Using a different tactic, Environmental Packaging International, also offers help to clients who are interested in selecting the most sustainable and appropriate packaging methods. The Packaging Impact Quick Evaluation Tool (PIQET) is a Web-based streamlined lifecycle assessment and ecodesign tool used for packaging design.

PIQET can be used to benchmark the current sustainability performance of packaging, review and optimize current packaging to improve sustainability performance and train people to make more sustainable decisions.

Through a Web-based interface, PIQET users provide the tool with packaging design information and details of the cradle-to-grave lifecycle of the packaging. The lifecycle includes the production of the raw materials used for making packaging products and the production, transport, filling and waste management of all the packaging products used in a particular design. Using the supplied information with background data sets developed from more comprehensive lifecycle assessment modeling, the tool analyzes the packaging system and reports on the sustainability performance of a particular packaging design based upon environmental lifecycle indicators including climate change, water use and solid-waste creation.

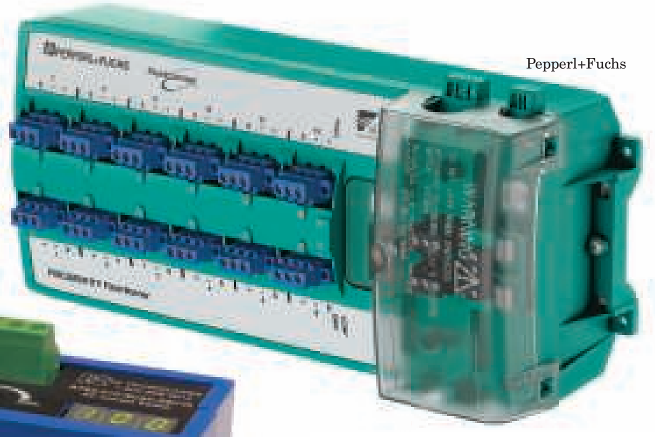
Experts in sustainable distribution stress that it is not just about using fewer resources, but instead it's about the bigger picture. "Our message to customers is all about first protecting what's inside the package, and then reducing damage to the environment," says Luijckx. "Product damage costs the supply chain a lot of money, costs the manufacturer a lot in lost sales and transportation costs and is also bad for the environment, so the goal of sustainable packaging and distribution should really be to prevent product damage via proper selection and use of the right type, material and amount of packaging." ■

Joy LePree

FOCUS ON

Automation and Control


Honeywell Process Solutions


Pepperl+Fuchs


NK Technologies

Ergonomic design, improved display reduces operator fatigue
The Experion Orion Console (photo) is an advanced display technology that builds on this company's flagship Experion Process Knowledge System (PKS) control platform. The console features a large flexible, ultra-high definition display that provides clear status assessments of process operations in a single glance for better and more informed management. This flexibility also enables operators to customize displays for context-specific process issues, and incorporates advanced alarm management and pan-and-zoom capabilities. Limits and targets are directly integrated into overview displays, allowing operation of the process closer to the optimum and allowing operators an increased scope of responsibility across the industrial facility. The console has a mobile tablet that also reduces operator fatigue by allowing personnel to move about the control room more freely than before. When paired with wireless-enabled mobile technologies, the system also allows operators to view the same displays on hand-held devices in other areas of the plant. — *Honeywell Process Solutions, Houston*
www.honeywellprocess.com

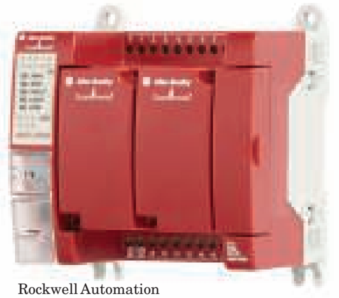
A current transducer and switch combined in a single package
The new ATS Series AC Current Sensors (photo) combine a current-operated switch and a transducer in a single package. The new design features a built-in digital display that provides a quick visual indication of where the contact changes, making setpoint adjustments easy and accurate. These sensors provide a solid-state contact that changes state when the current exceeds an adjustable level or falls below the normal running current. ATS current-operated sensors are advantageous over electromechanical pressure or flow devices because they prove more reliable electronic proof-of-operation, while eliminating the need for multiple pipe or duct penetrations, says the company. — *NK Technologies, San Jose, Calif.*
www.nktechnologies.com

This barrier has twelve outputs with diagnostics and monitoring
The new FieldConnex FieldBarrier (photo) has features that offer reliable protection against typical fault scenarios to ensure maximum reliability. FieldConnex FieldBarriers can detect the special dynamics of faults, such as loose contacts or contact bounces. As a result, faults can be identified and isolated both quickly and reliably. The new component is the first to allow monitoring of the physical layer at each FieldBarrier output. This enables gradual changes in the installation and faults in the control room to be reported. Another feature is the sophisticated load management. The twelve outputs start sequentially, reducing the load on the power supply from the inrush current. The FieldBarrier self-monitoring function can transmit alarm signals to the control room. — *Pepperl+Fuchs GmbH, Mannheim, Germany*
www.pepperl-fuchs.com

Software enhancements for this plant-resource manager
Plant Resource Manager (PRM) is a software package that is capable of centrally managing large amounts of data from plant monitoring and control devices and manufacturing equipment, thereby allowing their status to be monitored and diagnosed online. With PRM R3.12, self-diagnostic information is now displayed in a more intuitive, easy-to-understand format based on the Namur NE107 recommendations, and network functions have been enhanced for upstream oil-and-gas applications. This new version of

Note: For more information, circle the 3-digit number on p. 68, or use the website designation.

Mitsubishi Electric Automation



Rockwell Automation

PRM also offers enhanced network functionality, including improved support of wireless and satellite communications for upstream oil-and-gas applications. — *Yokogawa Corp. of America, Newnan, Ga.*
www.yokogawa.com

A flexible relay solution that simplifies safety implementation
Users can program the Allen-Bradley Guardmaster 440C-CR30 safety relay (photo) through the company's free Connected Components Workbench software. This software reduces programming time and helps increase productivity by allowing users to create, control and monitor a safety system in the same software environment as their standard control. The Guardmaster 440C-CR30 safety relay meets PLe, SIL 3 per EN ISO 13849-1 and IEC 62061 requirements. It is ideal for applications requiring four to nine safety circuits and control of up to five zones. With 22 on-board safety I/O points, including six configurable I/O, the relay is suitable for applications requiring multiple safety zones. — *Rockwell Automation, Milwaukee, Wisc.*
www.rockwellautomation.com

These transmitters now feature a switch-selectable output
A new version of the IPH2/IPX2 current-to-pressure (I/P) transmitter features updated certifications, as well as 22 direct and reverse output ranges, with switch-selectable reverse output standard on the IPX2. Another new feature on the IPX2 is a removable electronics module. In certain abnormal conditions, a liquid "slug" can enter the air or gas supply of the IPX2. The removable electronics module speeds the recovery process by allowing the liquid to drain more efficiently. The two-wire (loop-powered) IPH2 and IPX2 accept a current signal from a distributed control system (DCS),

programmable logic controller (PLC) or other control system and convert it into a pneumatic signal to provide precise, proportional control of valves, actuators and other pneumatically controlled devices. Both products meet NEMA Type 4X requirements, and the IPX2 can be installed in explosion-proof environments. — *Moore Industries-International, Inc., North Hills, Calif.*
www.miinet.com

This inverter preforms in any environment
The recently released A800 Series all-in-one variable frequency drive (VFD; photo, p. 31) combines traditional induction and permanent-magnet motors into a single solution, providing high performance response and energy-efficient motor control. It can be used in both induction motors and next-generation interior permanent motors, and is suitable for both low-performance applications, such as pumps and fans, as well as high-performance industrial applications. A800 VFDs are suitable as replacements for hydraulic-drive systems and gear motors in the process and material handling industries, and as replacements for inefficient motor-drive systems in the food-and-beverage industry. — *Mitsubishi Electric Automation, Vernon Hills, Ill.*
www.meau.com

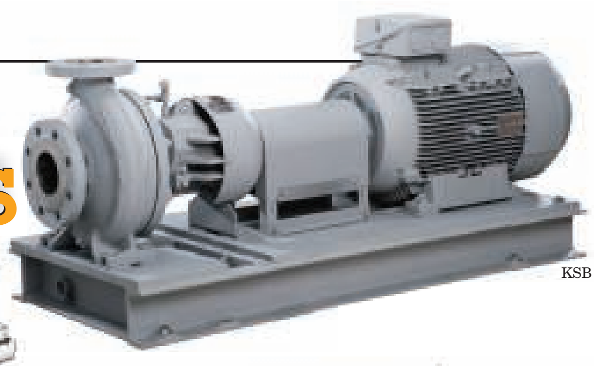
ICS Electronics

Modernize obsolete controllers with this converter
The Model 2399 (photo) is a new ANSI x3.28-to-Modbus RTU converter for controlling RS-232 and RS-485 Modbus RTU devices. This new converter was designed to simplify the replacement of controllers that use the ANSI X3.28 protocol. Many older production systems were designed with controllers that use the ANSI X3.28 protocol. These controllers are now obsolete. Maintenance on them is expensive and time-consuming. Replacing the old controllers with new models has been impractical up to now because the production system would have to be modified to work with a modern Modbus RTU-compatible controller. The 2399 makes the replacement possible without having to make any changes to the production system. — *ICS Electronics, Pleasanton, Calif.*
www.icselect.com ■

Gerald Ondrey

JULY

New Products



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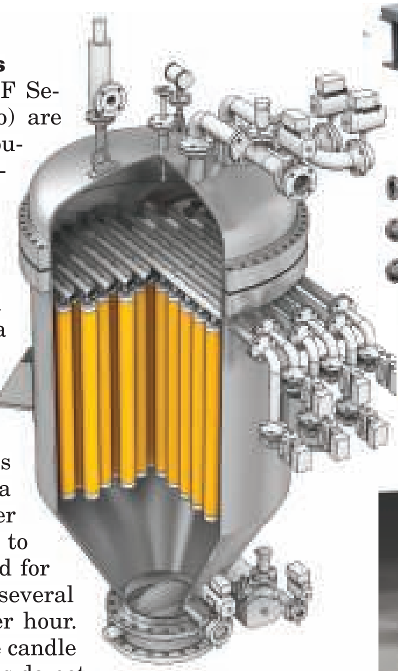

BHS-Sonthofen

Alfa Laval

Aker Solutions

Achieve clear filtrate with these candle filters

The further developed CF Series candle filters (photo) are particularly suitable for purifying industrial wastewater with low solids content. They have been specially developed for the filtration of liquids with solid concentration of less than 1% — an area of limited cake-building capabilities in which other filters fail. Even in the case of very fine particles with low solids content, they produce a clear filtrate. With filter areas ranging from 1 to 150 m^2, they are designed for throughput rates of up to several hundred cubic meters per hour. One special feature of the candle filter is that filtered solids do not form a sludge, but a pre-dried, semi-solid filter cake with a solids content of between 50 and 80%, thus significantly reducing the disposal volume compared with filter types with solids contents of 10 to 20%, says the company. — *BHS-Sonthofen GmbH, Sonthofen, Germany*
www.bhs-sonthofen.de

This recirculation pump doesn't need external cooling

Early this month, this company launched a new generation of hot-water recirculation pumps for large industrial heating systems as well as forced-circulation boilers and district heating systems. The horizontal, radially split single-stage volute casing pumps feature a back pull-out design. Their ratings and dimensions comply with ISO 2858; with regard to handling hot water, organic or synthetic heat-transfer fluids, they also meet the technical requirements of ISO 5199. The HPK-L pump series (photo), which comes in 49 different sizes, can be operated at temperatures of up to 400°C without any additional cooling devices, and is designed for pressure classes of up to PN 40. This temperature resistance is achieved by means of a generously sized heat barrier that separates the pump set's hot operating section from the air-cooled mechanical seal chamber. — *KSB AG, Frankenthal, Germany*
www.ksb.com

Heat or cool fibrous sludge with this tube-in-tube heat exchanger

This new tube-in-tube heat exchanger (photo) is designed for heating and cooling sludge that contains fibers and particles, making this equipment ideal for use with most kinds of wastewater sludge. The heat exchanger consists of a single tube mounted inside an outer shell tube. The sludge flows in one direction through the inner tube (corrugated or smooth), while the heating or cooling medium flows in the other direction between the inner and outer tubes. These heat-exchanger modules are normally connected in series and mounted on a frame. The layout can, however, be customized to fit into any available installation footprint, or to comply with other user requests. The standard design pressure is 15 bars on the product side and 10 bars on the heating/cooling side. The normal working temperature is 110°C. The unit can, however, work with higher pressure ratings and temperatures, depending on the thickness of the components and the type of connections used. — *Alfa Laval AB, Lund, Sweden*
www.alfalaval.com

A new slurry pump that handles high volumes

The new Wirth triplex double-acting piston diaphragm (TDPM) pump (photo) combines two well established and proven pumping principles for the transport of high volumes of abrasive slurry. The Wirth TDPM works on the triplex double-acting principle. It has flowrates of up to 1,400 m^3/h at a discharge pressure of up to 8 MPa in the 3,000 kW input power version. This is a significant increase in capacity compared to conventional piston diaphragm pumps, says the company. The Wirth TDPM 3000 can be used for traditional applications, such as slurry

Note: For more information, circle the 3-digit number on p. 68, or use the website designation.

Mettler Toledo

pipeline transport, autoclave feeding, mine dewatering and ore hoisting. Additionally, the pump is an efficient solution to pump thickened oil-sand tailings. — *Aker Solutions, Erkelenz, Germany*
www.akersolutions.com

Ensure safety and compliance with this new weighing terminal

This new ICS466x weighing terminal (photo) is designed for safe and accurate weighing in potentially explosive classified hazardous areas (Zone 1/21, Div. 1) to minimize risks of explosion and keep inspection and maintenance costs as low as possible. The ICS466x is intrinsically safe, which means it limits power output and prevents sparks or high temperatures in the electrical circuit that can ignite the surrounding atmosphere. It is built to withstand tough industrial environments with a stainless-steel housing that prevents corrosion. The ICS466x is available globally and complies with the latest hazardous-area regulations and standards, including ATEX, FMus+c and IECEx. — *Mettler Toledo Inc., Columbus, Ohio*
www.mt.com/ind-ICS466x

This blower is now even more energy efficient

The E-Blower extends the high-efficiency solution provided by the company's Delta Hybrid series in the low volume flow range. The new E-Design delivers a reduction of power demand of up to 4%, depending on volume flow and pressure difference, says the company. The savings are due, in part, to flow-optimized guidance of the intake air in the acoustic hood and in the filter silencer. A patented inlet cone (also used with Delta Hybrid rotary lobe compressors) not only minimizes the pressure loss, but also the noise emission. Additional savings are due to an electric motor-driven cooling fan, which replaces the shaft-driven acoustic hood-cooling fan. Six different sizes are available, with intake volume flows from approximately 30 up to 1,000 m³/h, and overpressures up to 1,000 bars or negative pressures up to 500 mbar. — *Aerzener Maschinenfabrik GmbH, Aerzen, Germany*
www.aerzen.com ■

Gerald Ondrey

CHEMICAL ENGINEERING
FACTS AT YOUR FINGERTIPS
Department Editor: Scott Jenkins

Liquefied-Industrial-Gas Safety

Many industrial gases are transported, stored and used in liquid form, a situation that poses significant health and safety risks. This one-page reference highlights good safety practices for preventing personnel injury when working with cryogenic fluids.

High-purity industrial gases, including nitrogen, oxygen, helium, argon and other noble gases, are commonly generated by air-separation units (ASUs), which typically use a cryogenic distillation process. Liquefied industrial gases, especially liquid nitrogen, are often delivered to end-users by cryogenic tankers into onsite vacuum-insulated storage vessels for on-demand use as a liquid or a gas. Among the myriad uses of industrial gases, several involve their use in liquid form. These include: R&D; cooling of process equipment (reactors, crystallizers, storage tanks and so on); lyophilization; recovery of volatile organic compounds; food freezing; cryogenic milling of solids; cryogenic preservation; plastic and rubber deflashing and grinding; and others.

Exposure hazards

The extremely low temperatures and high expansion rates (from a phase change) that characterize liquefied gases present health and safety hazards.

Cryogenic burns and frostbite hazards. Cryogenic liquids and cold gas that come in contact with human skin can cause serious damage to living tissue, including cold burns and frostbite. Damage can occur with exposures of longer than a few seconds, especially to delicate tissues, such as the eyes.

High-pressure gas. Storing cryogenic fluids presents hazards from high-pressure gas, since the liquefied gases are usually stored at or near their boiling points (see Table 1). Large expansion ratios on vaporization can cause a buildup of high pressures. The evaporation rate depends on the fluid, storage-container design and environmental conditions, but all storage containers should allow for the evaporation of the liquid.

Displacement of oxygen/asphyxiation. Because of the large expansion when a cryogenic fluid evaporates, it can cause asphyxiation by displacing breathable air. Natural ventilation should be ensured, and transporting and using cryogenic fluids in enclosed spaces should be avoided. In normal dry air, oxygen makes up 20.95% by volume. No one should enter an area where the oxygen concentration is below 19.5% without self-contained breathing equipment.

Flammability. In the case of cryogenic gases that are flammable, including hydrogen, methane and acetylene, ignition sources must be prohibited. Flammable materials must be stored away from liquid oxygen areas, since O_2 supports and accelerates combustion. Be aware that liquefied inert gases and extremely cold surfaces can condense oxygen from the atmosphere, causing oxygen entrapment in unsuspected areas.

Safety practices

Tasks with the potential for exposure to cryogenic liquids should only be conducted by competent staff members who have received appropriate training on specific health and safety risks, standard operating procedures and actions to be taken in the event of an exposure.

Personal protective equipment (PPE). Cryogenic exposure is often attributable to inadequate PPE. Where the potential for cryogenic exposure exists, all personnel should use the following PPE:

- Eye protection, with a full-face shield over safety glasses, should be used when transferring liquids to an open container
- Gloves should either be designed to prevent cryogens from flowing into the glove or be loose fitting so the glove can be easily shaken off after accidental contact. Cotton or nylon gloves covered with disposable nitrile or vinyl gloves are recommended for work that requires delicate handling of cold items in close proximity to liquid nitrogen, but are not designed to allow immersion of hands and fingers into the liquid
- Laboratory coats, disposable coveralls or long-sleeved shirts and pants that provide complete coverage of skin not otherwise protected by PPE or attire, should be worn

Contact. Cryogenic liquids and uninsulated cryogenic equipment and pipes should generally not not be directly touched. Tongs can be used to withdraw objects immersed in a cryogenic liquid. All parts of the body must be protected from uninsulated pipes or vessels containing cryogenic liquids, because the extremely cold metal may stick fast to the skin and tear the flesh upon removal. Watches, rings and jewelry should not be worn (metals can become frozen to the skin).

Handling. The following are tips for safe handling of cryogenic liquids.

- Do not overfill containers
- Pour slowly to minimize splashing
- Avoid the path of boil-off gases
- Ensure that cryogenic fluids are stored in appropriately insulated containers, which minimize the loss of product due to boil-off
- Containers of cryogenic liquid should be allowed to vent. Where a special vented stopper or venting tube is used, as on some small portable containers, the vent should be checked regularly to ensure it has not plugged with ice formed from condensed water vapor from the air
- The materials used in cryogenic systems must have the appropriate physical properties to qualify them for use at extremely low temperatures. Acceptable materials include aluminum, copper, brass, fiberglass and stainless steels (304 and 316)

Pressure relief. The follow are tips related to pressure relief:

- All system vents must be directed away from personnel or designated work areas
- Venting fluids should not impinge on any part of the body. Ensure that pressure-relief devices are checked, maintained and sized for maximum backpressure
- Ensure all safety valves and vent valves are unobstructed and functioning properly. Check the safety vents on liquid nitrogen tanks at least twice a week
- Ensure that an oxygen alarm is present in the work area when appropriate

Spills. If cryogenic material is spilled skin contact is involved, immediate medical attention is required. Large spills (especially in a confined space) can lead to an oxygen-deficient atmosphere, so personnel should be evacuated from the area.

TABLE 1. PROPERTIES OF COMMON INDUSTRIAL GASES

Substance	Chemical symbol	Boiling point, °C (at 1 atm)	Density, kg/m³	Latent heat of vaporization, kJ/kg
Air	–	–194.3°C	1.29	205.0
Nitrogen	N_2	–195.8 °C	1.25	199.1
Helium	He	–268.9°C	0.18	20.28
Oxygen	O_2	–183.0 °C	1.43	213.0
Argon	Ar	–185.9°C	1.78	162.3
Acetylene	C_2H_2	–83.3°C	1.17	614.0
Hydrogen	H_2	–252.8°C	0.09	446.0
Ethane	C_2H_6	–88.6°C	1.36	489.4
Methane	CH_4	–161.5°C	0.72	509.9
Neon	Ne	–246.0°C	0.90	86.3
Xenon	Xe	–108.2°C	5.85	96.3
Carbon dioxide	CO_2	–78.5°C	1.25	571.3
Ammonia	NH_3	–33.3°C	0.77	1,371.0
Krypton	Kr	–153.4°C	3.71	107.5

References

1. Cryogenic Safety Manual. Argonne National Laboratory, Physics Division. Available at: www.phy.anl.gov.
2. OSHA Laboratory Safety Guidance, OSHA 3404-11R, U.S. Department of Labor. 2011.
3. Virginia Commonwealth Univ., Cryogenics safe work practices. 2009. www.vcu.edu/oehs.

Producing Ethanol from Lignocellulosic Biomass

By Intratec Solutions

Pressing global issues, such as climate change and declining energy security, have led to an increasing interest in the use of renewable feedstocks for fuel production. These feedstocks include lignocellulosic materials, such as waste biomass from the agriculture and forest industries.

Ethanol is commonly produced by fermentation of sugars from agricultural feedstock — mostly corn and sugarcane. Several processes to produce ethanol by fermenting lignocellulosic materials have been developed. Two such processes have been introduced by American Process Inc. (Atlanta, Ga.; www.americanprocess.com), one of which was covered in this column last year (*Chem. Eng.*, November 2013, p. 26). The other cellulosic ethanol process is discussed below.

The process

The process for cellulosic ethanol production depicted in Figure 1 is similar to the AVAP process described in the World Intellectual Property Organization (Geneva, Switzerland; www.wipo.int) patent published by American Process Inc. (W.O. Patent 2011/044378A1).

Pretreatment. The biomass is heated with a solution of SO_2, ethanol and water and then fractionated into its three lignocellulosic components: hemicellulose, cellulose and lignin. Hemicellulose and lignin are partially dissolved, while cellulose remains insoluble. Cellulose is washed and the filtrate is sent to the stripping column, where SO_2 and ethanol are recovered in the overhead stream, which is condensed in an evaporator and sent to a make-up vessel. The column bottoms material is concentrated in the evaporator, generating vapor that is compressed and used as steam supply for the evaporator and for the column's reboiler.

Cellulose hydrolysis and fermentation. Cellulose is hydrolyzed into glucose monomers by an enzymatic reaction. Insoluble lignin is separated and conducted to the hemicellulose hydrolysis area and glucose is fermented to ethanol. The broth is centrifuged, then the cells are treated with sulfuric acid and recycled to the fermenters.

Hemicellulose hydrolysis and fermentation. The concentrated stream from the pretreatment area is mixed with the lignin from the enzymatic hydrolysis and pumped to the auto-hydrolysis reactor, where hemicellulose is hydrolyzed to monomer sugars, such as xylose. The hydrolyzate is neutralized with lime to precipitate the soluble lignin. Insoluble lignin is separated and burned to generate steam and energy to supply plant demands. The monomer sugars are fermented to ethanol.

Distillation. The broths from the fermentation steps are mixed and conducted to the concentration column, where a vapor side stream with 50% ethanol is obtained. The bottoms material from this column is used to wash cellulose. The side stream is fed to the rectifying column, generating an overhead stream containing about 93% ethanol. The ethanol product stream undergoes dehydration in a molecular sieve unit, leading to ethanol product with 99.5% purity.

Key research features

Regarding its process, American Process says the following:

- The application of enzymes only for cellulose hydrolysis requires a lower dose of enzymes when compared to processes converting both cellulose and hemicellulose by enzymatic hydrolysis
- The process offers an energy-efficient recovery of cooking chemicals, resulting in low expenses with chemical make-up

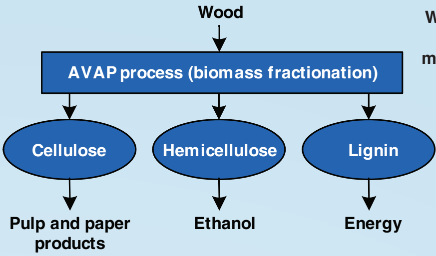

FIGURE 2. Wood fractionation for the manufacture of different final products

Economic performance

An economic evaluation of the process was conducted, taking the following assumptions into consideration:

- A biomass processing unit producing 58 million gallons of anhydrous ethanol per year, built on the U.S. Gulf Coast
- Storage of products is equal to 30 days of operation, and there is no storage for feedstock

The estimated capital expenses (including total fixed investment, working capital and other expenses) for the construction of this plant are about $700 million.

An interesting application to the presented technology is its integration with the pulp-and-paper industry. In this case, the process can fractionate wood into its primary components (cellulose, hemicellulose and lignin). Then, each fraction can be used in different applications, targeting each toward the most profitable market (Figure 2). ■

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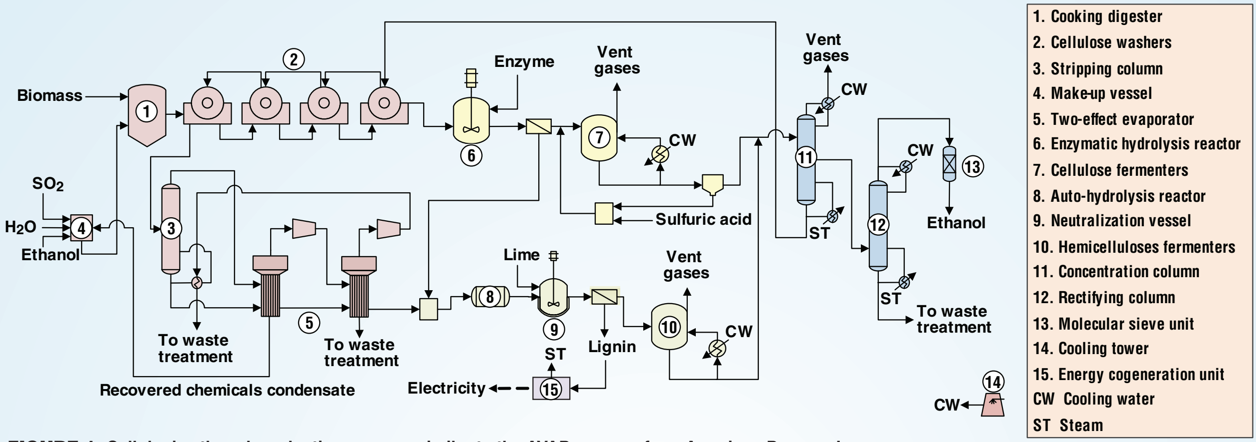

FIGURE 1. Cellulosic ethanol production process similar to the AVAP process from American Process Inc.

Cover Story

A Primer on Reverse Osmosis Technology

Desalination by reverse osmosis is a key technology for a water-constrained world. Discussed here is its use in industrial water treatment and drinking-water production

FIGURE 1. Reverse osmosis has become the most efficient and versatile technology for desalination and water purification

Richard L. Stover
Desalitech, Inc.

Water scarcity is one of the most serious global challenges of our time. Desalination and water reuse are effective and reliable means to provide new water resources. Among the many methods available to treat water, reverse osmosis (RO) has widely demonstrated superior reliability and cost-effectiveness at removing dissolved species, such as salts and trace contaminants. This article reviews the development and state of the art of RO for industrial water treatment, wastewater treatment and drinking water production. It also reviews technological advances that have improved process performance, reliability and reduced cost, and describes currently available components and methods. Finally, it considers the prospects for future advances in the field.

Water scarcity and desalination

The world's freshwater resources are under tremendous pressure. Over one-third of the world's population lives in a water-stressed country, and by 2025, this figure is predicted to rise to nearly two-thirds of the global population [*1*]. Industrial operations consume an estimated 60% of all freshwater withdrawals in developed countries like the U.S. Together, industry and agriculture are responsible for about 90% of the freshwater consumed globally [*2*]. Efficient and sustainable water treatment methods for industrial and agricultural water supply are imperative.

Water should be conserved, recycled and reused to reduce the stress on water supplies, but this will not meet the increased demand posed by population and economic growth. The treatment of salty water resources and wastewater reuse offers new and reliable sources of freshwater, without impairing existing freshwater resources. Today, an estimated 300 million people in 150 countries already rely on desalinated water. In 2016, the global water production by desalination is projected to exceed 10 trillion gal/yr (38 billion m^3/yr) — twice the rate of global water production by desalination in 2008 [*3*].

Early desalination and water purification methods included distillation, which uses large amounts of energy to evaporate freshwater from saltwater [*4*]. Distillation plants for desalination still operate today in some regions of the world where energy is abundant and inexpensive. However, the vast majority of desalination and water-purification plants that have been constructed recently or are planned employ RO technology.

Thanks to technological improvements over the last 20 years, the cost to produce freshwater with RO has been reduced by a factor of four or more, and the process has become a reliable component of municipal and industrial infrastructure (Figure 1). At present, RO is the most energy-efficient and versatile technology for desalination and water purification and is the benchmark for comparison for any new water-purification technology [*5,6*].

RO is most commonly known for its use in purifying drinking water from seawater, brackish water or contaminated water, where RO removes salt and other dissolved or suspended materials from feedwater. Many are surprised to learn that its use in other applications is widespread and well-established. For example, RO is used to remove

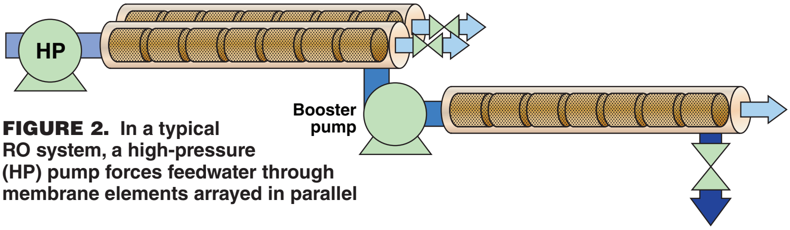

FIGURE 2. In a typical RO system, a high-pressure (HP) pump forces feedwater through membrane elements arrayed in parallel

minerals from boiler water at power plants, to clean effluent and brackish groundwater, and for concentrating food liquids, such as milk.

Reverse osmosis principles

Osmosis is the natural movement of water from an area of high water concentration (low salt concentration) through a salt barrier to an area of low water concentration (high salt concentration). Flow is driven by the difference in osmotic potential of the two solutions, quantified as osmotic pressure. Applying an external pressure to reverse the natural flow of water through the barrier is RO.

The process of osmosis through a semipermeable membrane was first observed in 1748 by Jean-Antoine Nollet. RO was known in the 1950s, but was not practically demonstrated until the early 1960s, with the discovery of asymmetric membranes at the University of California at Los Angeles (www.ucla.edu) by Sidney Loeb and Srinivasa Sourirajan [7]. These membranes were characterized by a thin "skin" layer supported atop a highly porous and much thicker substrate. This basic structure remains the basis of modern RO membranes.

When a salt solution is pressurized against an RO membrane, impurities are retained on the pressurized side of the membrane as brine and purified water flows through the membranes as permeate. RO requires flow across the membranes, known as crossflow, to keep the membrane surfaces clear of concentrate and allow continuous and almost constant flow of permeate. This differs from conventional filtration processes, in which impurities embed in the filter or build up as a cake that must be backflushed or removed periodically to restore productivity.

The minimum pressure required to separate pure water from impure water can be considered as a barrier. The height of this barrier depends upon the osmotic pressure or osmotic potential of the water, which in turn depends upon its salinity and composition. Saltier water has a higher osmotic potential and requires more pressure to desalinate. To drive permeate through membranes at reasonable fluxes, the osmotic potential must not only be met, but overcome. This overpressure depends partly upon the permeability of the membranes. In addition, the salt concentration immediately adjacent to the membrane surface is elevated, which increases the osmotic barrier above that in the bulk of the saltwater — a phenomenon known as concentration polarization. Concentration polarization is reduced with crossflow.

Other non-idealities in RO systems that elevate energy requirements include resistance to flow through the membranes, mechanical and volumetric efficiency losses in pumps and viscous friction losses in flowing water. Also, membrane surfaces can be blocked with contaminants, including organic and inorganic foulants or salts that precipitate out of solution.

For RO treatment of brackish, industrial and wastewater (collectively referred to here as industrial RO) salinity levels and the corresponding feed pressure requirements are typically lower than those for seawater RO. Therefore, energy requirements are usually not a major cost consideration. However, the cost and practicality of brine disposal and the need for the process to handle feed composition changes are more significant in industrial RO applications. To limit brine production and achieve a high yield of purified water, industrial RO systems operate at high recovery rates, where recovery is defined as the ratio of permeate flow to source-water flow. However, high recovery increases the risk of membrane contamination, presents challenges for maintaining crossflow, reduces permeate quality and can reduce the flexibility of the process to handle feedwater variations.

Many of these challenges have been met with emerging technologies that enhance the utility of RO.

RO systems

RO membranes are incorporated into systems that deliver source water to the membranes, apply crossflow that sweeps concentrate from the membrane surface, and provide a pathway for conveying water that permeates through the membranes. The primary components of an RO system are the membrane elements, the pumps and the devices used to manage flow and pressure. Typically, a high-pressure pump provides both the driving force for the separation and the crossflow, but several current process designs use a circulation pump to drive crossflow, so that the role of the high-pressure pump is reduced to pressurizing the system and driving permeate flow.

RO process configurations

A typical system for industrial RO is shown in Figure 2. A high-pressure (HP) pump feeds the system. Pressure vessels containing multiple membrane elements are arrayed in parallel. Each pressure vessel contains six or seven membrane elements in series, with the concentrate of each element being fed to the subsequent element. One stage typically achieves 50% recovery, and higher recovery rates require multiple stages. The productivity of multiple stages are balanced by throttling the permeate flow from front stages and boosting feed pressure to later stages with a booster pump (BP). The number of pressure vessels arrayed in parallel in each subsequent stage is reduced to maintain sufficient crossflow in later stages. Finally, brine is

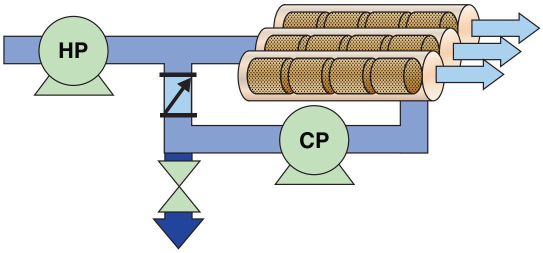

FIGURE 3. Closed-circuit RO processes utilize brine recirculation to achieve high recovery without multiple stages

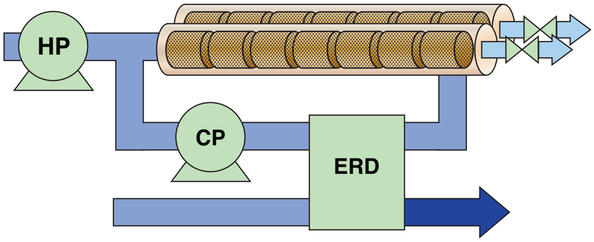

FIGURE 4. Seawater RO processes require higher pressures that those in industrial RO, making energy consumption more important

throttled out of the system through a valve or a device that regulates system pressure.

At 50% recovery per stage, four stages are required to achieve over 90% total recovery. Multiple stages add design and operational complexity and reduce process flexibility. Alternately, recovery can be increased by continuously returning some of the brine to the membrane feed. However, the increase in feed, brine and permeate salinity caused by brine recirculation usually undermines the benefits it provides.

Emerging closed-circuit (semi-batch) RO processes, which utilize brine recirculation in a batch-like operation, provide a new means to achieve high recovery without multiple stages or reduced permeate quality [*8,9*]. Such a process is illustrated in Figure 3. A high-pressure pump feeds a closed loop comprised of a single-stage of membrane elements and a circulation pump (CP). Permeate is produced at a rate equal to the flowrate of the HP pump. Brine is recirculated without depressurization. When a desired recovery percentage is reached, brine is flushed out of the system, displaced by feedwater from the HP pump. The exchange of brine and feedwater is executed without stopping the HP pump or producing permeate and without depressurizing the system. The process then returns to closed-circuit operation, during which there is no brine reject stream.

Over 97% recovery has been achieved in closed-circuit RO processes. Energy requirements are reduced because the average membrane feed pressure required to achieve a given recovery rate is lower. The ability to change recovery at the control panel provides substantial flexibility. The frequent flushing of the system by the brine-feedwater exchange also helps suppress fouling and scaling, such that higher recovery rates can be sustained.

In seawater RO, higher pressures are generally required than those used in industrial RO. This makes energy consumption more important and it limits recovery rates. A typical seawater RO process is illustrated in Figure 4. Like in the closed-circuit industrial RO system, the seawater process uses both a high pressure pump and a circulation pump to feed the membrane array. In addition, an energy recovery device (ERD) is used to remove brine and replace it with feedwater while maintaining system pressure. These devices save energy by recovering hydraulic energy from the reject brine and returning it to the low-pressure feed process, thereby reducing the duty of the HP pump.

For lower-recovery, higher-pressure applications, such as brine concentration and seawater desalination, an alternative closed-circuit process is used to minimize energy requirements [*10,11*]. In this process configuration, brine is displaced from the membranes with pressurized feedwater from a side chamber. The exchange, emptying and refilling of the side chamber is done under hydrostatic conditions with almost no loss of pressure energy.

Membranes

RO processes are built around semipermeable membranes capable of filtering out salts. The first membranes were made of cellulose acetate and served as the best available technology until the 1980s, when robust thin-film composite (TFC) membranes were developed [*12*]. TFC membranes exhibit much higher intrinsic water permeabilities than cellulose acetate membranes because of their extremely thin selective layers. Today, nearly all RO operations use TFC membranes [*13*]. Despite the great improvements in TFC membrane performance and cost, there are still shortcomings that hinder their application. These limitations include being prone to fouling and being susceptible to attack by oxidizing agents, such as chlorine.

Pumps

The high-pressure pump supplies the pressure needed to push water through the membranes and, in the process illustrated in Figure 1, supplies the crossflow that controls concentration polarization. Typical pressures for industrial water treatment range from 150 to 450 psi (10 to 31 bars). Seawater RO pressures range from 750 to 1,200 psi (52 to 83 bars). Typically, centrifugal-type pumps are used, with sufficient stages and features to meet the pressure requirements. In some high-pressure applications, positive-displacement pumps are preferred because of their generally higher efficiency.

The interstage booster pump shown in Figure 1 adds enough pressure to the concentrate stream to overcome its increased osmotic pressure in later stages. Like the HP pump, the booster pump drives both permeate flow and crossflow. It is sized and operated to "balance" flux and flow between the stages so that all individual membrane elements operate within their design envelopes and are neither over- nor under-utilized. Typical boost pres-

TABLE 1. APPROXIMATE COSTS OF A 367 gal/min (2,000 m³/d) INDUSTRIAL RO UNIT (10-yr life)								
Industrial RO		75% Recovery				90% Recovery		
	Present value, 10 yr	Cost, gal/d	Cost per 1,000 gal	Percent of otal	Present Value, 10 yr	Cost, gal/d	Percent of total	Cost per 1,000 gal
Capex	$521,195	$0.99	$0.28	6%	$521,195	$0.99	12%	$0.28
Energy	$480,727	$0.91	$0.26	6%	$600,909	$1.14	14%	$0.32
O&M	$1,148,252	$2.17	$0.62	13%	$1,148,252	$2.17	26%	$0.62
Brine	$6,436,578	$12.18	$3.48	75%	$2,145,526	$4.06	49%	$1.16
Total	$8,586,752	$16.25	$4.64	100%	$4,415,882	$8.36	100%	$2.39

sures for industrial water treatment range from 40 to 200 psi (3 to 14 bars). In some process configurations, a hydraulic turbocharger is used as an inter-stage booster pump, driven by flow and pressure of brine from subsequent stages.

The role of the circulation pump shown in Figures 2 and 3 is to provide crossflow. These pumps only supply enough pressure to overcome friction losses in the flow channels in order to achieve the desired crossflow rate. Typical applied pressures range from 10 to 50 psi (0.7 to 3.4 bars). The circulation pump must be equipped with a shaft seal and bearings designed to handle the incoming pressure of the brine.

Energy recovery devices

Energy recovery devices (ERDs) are installed in the brine stream of seawater RO processes to recover the otherwise wasted hydraulic energy. Initially, these devices were reverse-running pumps or turbines that were mechanically coupled to the HP pump. Net energy-transfer efficiency — the product of turbine efficiency and pump efficiency — could be as high as 80% with very large devices. In the early 2000s, isobaric ERDs were introduced, allowing direct transfer of pressure from the reject stream to the membrane feed stream. These devices offer net transfer efficiencies of 90% or more, and reduce the size and of the HP pump [*14*]. Turbine ERDs are currently used in some seawater RO applications because of their relatively low cost. ERDs are not typically applied in industrial RO installations because the brine stream does not contain enough energy to justify their cost.

Costs

The cost of water generated by an RO plant comprises capital costs (CAPEX) and operating costs (OPEX). CAPEX per volume of water produced depends upon the construction cost and the amortization rate of the plant, the interest rate (the desired yield on the capital investment) and the plant utilization (load factor). OPEX consists of the fixed costs of staff, insurance and so on, as well as the variable costs of operation and maintenance and repair (including consumables). Energy costs are directly proportional to the price of power and include the pumping energy directly consumed for RO and the energy used for pretreatment, post-treatment and overall plant operations. Additional costs can be incurred for obtaining feedwater and disposing of brine concentrate.

Industrial RO

Assuming typical financial and utilization factors, the CAPEX of an industrial RO unit depends primarily upon the composition of the water being treated and the cost of pre- and post-treatment. However, many industrial RO units can be installed within existing facilities or housed in containers, reducing or eliminating the cost of civil work. The approximate costs for a typical industrial RO unit with a permeate production capacity of 367 gal/min (2,000 m³/d) at a recovery rate of 75%, assuming a 10-year unit life, is summarized in Table 1. About 70% of the CAPEX indicated is for the equipment, and the balance is for installation. Operation and maintenance (O&M) costs are estimated at $0.57 per 1,000 gal. Brine disposal costs are based on an average U.S. commercial sewage fee of $7.60 per 1,000 gal [*17*].

The values in Table 1 clearly indicate that brine disposal is the largest expense item for industrial RO. In this example, increasing recovery from 75% to 90% only slightly increases energy consumption but reduces brine disposal costs by a factor of three, and cuts the overall cost of ownership almost in half.

Seawater RO

Seawater RO installations are typically larger than industrial RO installations, and are tendered for up to 25-year expected lifetimes. A typical CAPEX requirement for a mid-scale seawater RO plant in 2008 was approximately $6 per gallon per day ($1,585 per m³/d) of permeate output, installed. Therefore, a 10-million gal/d (38,000 m³/d) plant costs approximately $60 million to build. OPEX is approximately $0.57 per 1,000 gal (about $2.8 million/yr for a 10-million gal/day plant [*15*]. With a typical energy requirement of 3.2 kWh/m³, including pre- and post-treatment and a power tariff or energy price of $0.10/kWh, the energy cost for a 10 million gal/d plant is $4.4 million per year. The resulting present value costs for 25 years of operation are presented in Table 2.

The data in Table 1 indicate that energy comprises more than half the total cost of a 25-year seawater RO operation and more than triple the capital cost of building the plant. Energy-saving methods and technologies can be easily cost-justified. For example, a 5% reduction in seawater RO energy consumption in the 38,000 m³/d (10 million gal/d) plant considered above would save over $7 million in present value. This value is equivalent to 12% of the cost of ownership of the plant. If a 5% energy savings required a 1% increase in the overall cost of the plant, the investment would be paid back in about three years.

For context, it should be noted that most methods of delivering large quantities of water are expensive. Traditional water distribution and treatment requires building plants and infrastructure. In the developed world, the price to

TABLE 2. PRESENT VALUE COSTS FOR A 38,000 m^3/d (10 million gal/d) SEAWATER RO PLANT FOR 25 YEARS								
Seawater RO		Typical energy consumption				5% Reduced energy consumption		
	Present Value, 25 years	Cost, gal/d	Cost per 1,000 gal	Percent of total	Present Value, 25 years	Cost, gal/d	Cost per 1,000 gal	Percent of total
Capex	$60,004,542	$6.00	$0.66	14%	$60,004,542	$6.00	$0.66	15%
Energy	$216,953,081	$21.69	$2.38	52%	$209,569,720	$20.96	$2.30	51%
O&M	$138,571,724	$13.86	$1.52	33%	$138,571,724	$13.86	$1.52	34%
Total	$415,529,347	$41.55	$4.55	100%	$408,145,986	$40.81	$4.47	100%

produce 1,000 gal from traditional water supplies ranges from $6 to 15 ($1.52–3.88 per m^3) [*17*]. A comparison of these figures to the costs listed above makes it clear that RO can be a cost-competitive means of water supply.

Potential technology advances

Technology for RO desalination continues to improve. Here are some possible future advances for the key components of RO operations, and their potential value.

Membranes. Ultrahigh-permeability membranes, including graphene membranes or TFC membranes made with carbon nanotubes or aquaporins, have recently received a lot of attention for their potential to reduce the pressure needed to drive permeation, thereby reducing the energy demand of RO [*18*]. However, high permeability typically reduces salt rejection. Assuming salt rejection can be improved, the amount of energy that can be saved by using ultrahigh-permeability membranes is likely to be very small. Current RO plants already operate near the thermodynamic limit, with the applied pressure being only 10 to 20% higher than the osmotic pressure of the concentrate. Some of this excess pressure is needed to drive crossflow past whatever membrane material is used. Although these membranes might make it possible to use less membrane area and therefore save on capital expense, this would require a redesign of membrane elements because concentration polarization induced by high water fluxes already hinders the performance of current thin-film composite membrane elements. Additionally, membrane fouling is exacerbated at higher water fluxes, further diminishing the value of ultrahigh-permeability membranes for RO.

Reducing or eliminating pretreatment could reduce the cost of RO, but this would require the development of fouling-resistant membranes or membrane coatings. Advances in membrane technology can also reduce the need for the post-treatment currently required for lowering boron and chloride concentrations in permeate to levels suitable for agricultural use. However, membranes with better selective-ion rejection are generally less permeable to water, which increases feed-pressure requirements and energy consumption.

Pumps and ERDs. Although there have been no significant improvements in pump or motor efficiencies specifically for RO applications, pump and plant designers can reduce energy consumption with smart process designs. These include the use of larger centrifugal pumps, with inherently higher efficiencies, and variable frequency drives (VFDs) instead of throttle valves for flow and pressure control. Although VFDs for very large motors can be cost-prohibitive, the HP pump can be fed with a feed booster pump that is equipped with a VFD. A properly controlled booster pump can allow both pumps to operate close to their best efficiency points despite varying process and feedwater conditions. In addition, the use of a feed booster pump allows the use of a HP pump with a higher net positive suction head, which can increase pump efficiency.

Despite the apparently advanced state of isobaric ERDs, innovation continues to broaden the applicability of these devices, improve their performance and reliability, and ultimately reduce the capital and operating costs of seawater RO. ERD efficiencies could be increased by installing additional ERD units, thereby reducing the flowrate to each unit and reducing differential pressure losses, by tightening valve seals and by lowering brine exit velocities [*19*].

Advanced process designs. The use of multiple stages can lower feed pressure requirements to near the theoretical minimum pressure requirements [*20*] and potentially allow for more balanced membrane operation. However, the pressure of the concentrate from the final stage is much higher than the feed pressure of the first stage, making it impossible to use isobaric energy-recovery devices in multistage configurations, undermining some of the energy-savings potential of these designs for seawater RO. Also, the additional pumps required add capital costs.

Closed-circuit RO operations provide the energy-saving benefits of multistaging without the need for energy-recovery devices or additional pumps. They facilitate operation at high recovery rates, lowering brine production, the disposal of

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which is the largest cost component in most industrial RO applications.

Forward osmosis. Forward osmosis uses a water-permeable and salt-rejecting membrane between two solutions of different osmotic pressures. These solutions can be natural resources, waste streams or high-purity solutions. Natural osmosis drives water to permeate through the membrane from the less salty "feed solution" to the more salty "draw solution." Engineered draw solutions employ specifically selected draw solutes that are separated from the extracted water and recycled to facilitate continuous forward-osmosis operation. However, draw solution regeneration is a cost-intensive step [*21*]. A recently proposed design is a hybrid system that uses a forward-osmotic contactor to dilute seawater with wastewater effluent prior to RO treatment [*22*]. However, this system requires two-membrane operation, which adds costs and, for potable water production, the negative public perception about utilizing wastewater effluent as a potable water supply would need to be overcome.

Concluding remarks

Reverse osmosis is a reliable, cost-effective and well-established means of purifying water for domestic and industrial use. RO component and process designs have improved in recent years, lowering water treatment costs. For most industrial RO applications, raising recovery, thereby reducing waste brine generation, represents the greatest cost-saving opportunity. For seawater RO, reducing energy consumption has the greatest prospect for lowering overall costs. Anticipated future technological advances could provide recovery increases and additional energy savings, particularly with closed-circuit RO process designs. ■

Edited by Scott Jenkins

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Feature Report

CONTROL VALVE SELECTION: True Cost Savings Are Available

FIGURE 1. Control valves are vital in a variety of industrial applications. Proper design and sizing lead to proper selection, and, ultimately, optimal installation and performance

Control valves must respond quickly and accurately in a variety of process conditions. Selecting the proper equipment enhances process economics, safety and efficiency

Vesa Lempinen
Metso Automation, Inc.

New safety and environmental regulations, longer plant uptime and changes in maintenance practices have created new requirements across the chemical process industries (CPI). Among the plant equipment affected by these changes are control valves, since they are used in numerous applications in a variety of process conditions. Figures 1 and 2 show typical control valves installed in CPI plants. The primary function of a control valve and its associated control loop are to respond to process and setpoint changes as quickly and accurately as possible, in order to provide sound process control as desired and to avoid disturbances. The selected control valve must provide reliable, safe and robust operation under all process-load conditions, as well as withstand the flow medium, including any possible damaging or hazardous impurities that might be present.

Stable process control improves production yield and efficiency. As such, correct control-valve selection has a huge effect not only on process control, but also lifecycle costs. Therefore, control-valve selection should be viewed from an economic as well as a process standpoint. Selection of a control valve for a specific process application should be based on real process conditions and application demands. Valve application know-how, together with modern sizing tools capable of modeling a valve's installed behavior accurately, are important factors in finding the right control-valve solution for a specific situation. These tools can also predict possible problems that may arise. If the valve's installed behavior isn't properly taken into account, there is a higher risk for performance issues. Consistency in installed characteristics is very important in ensuring that the valve will properly control the process over the entire range of required operational conditions for a given application. Otherwise, the control valve may act too slowly at some operational points, and may overshoot (open or close too quickly) at other times.

FIGURE 2. Correct control-valve selection enables seamless process operation, even in demanding process or environmental conditions

The control valve's role in plant profitability should never be overlooked. Often, a valve's performance value is not seen until something goes wrong and the control valve must go off duty, begging the question: why do some control valves fail frequently while others operate continuously for many years with minimal maintenance? The answer lies in understanding the importance of selecting the most appropriate control valve for a specific application. This article seeks to explain the reasoning behind control-valve selection, including design and financial considerations, and also to provide some application recommendations for various control-valve types.

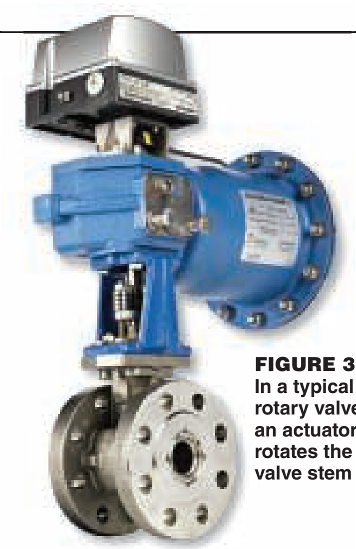

FIGURE 3. In a typical rotary valve, an actuator rotates the valve stem

FIGURE 4. Linear valves are of the globe valve family and are the preferred valve type for high-pressure applications

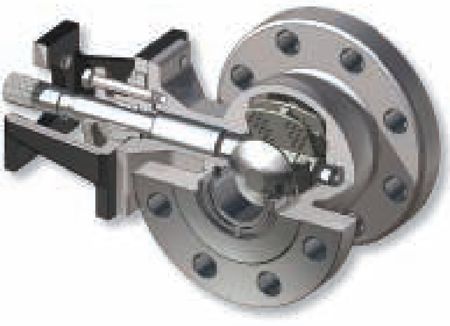

FIGURE 5. The simpler internal structure of rotary valves when compared to linear valves makes them more suitable for service where impurities are present in the fluid

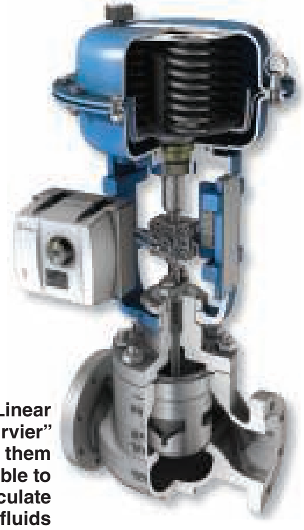

FIGURE 6. Linear valves have a "curvier" structure, making them more susceptible to erosion from particulate matter in fluids

Lifecycle versus purchasing cost

Traditionally, the direct purchasing cost of devices has been seen as the primary source of savings, sometimes even at the expense of device quality and performance. However, estimates indicate that only 10–30% of the total ownership costs of control valves are related to the valve's purchase price, whereas the remaining 70–90% of costs can be attributed to maintenance, repair and operation (MRO). Of course, it is also important to consider the total financial impact of device failures on plant production. Seen from this point of view, it is clear that correct control-valve selection has a major impact on process efficiency and operating costs, because proper valve selection can help to avoid failures and ensure optimal performance. A small savings in purchasing costs upfront at the expense of device quality may result in much larger expenses through process upsets and device maintenance costs later on. An investment in the correct valve selection typically sees a positive return on investment relatively quickly.

With well-designed and correctly selected control valves, process plants can reduce costs related to operation and maintenance of control valves. Also, selecting the correct control valve provides clear cost savings through improved control performance and accuracy. The financial effect of enhanced process stability, improved efficiency and lower energy and raw material consumption can add up to be much greater than the savings on maintenance costs — more than enough to offset the savings of purchasing a less expensive valve that is not as suitable for the application.

Another cost factor that must be considered is the benefit of purchasing intelligent valve technology, such as smart controllers, for valves. This consideration is discussed in further detail later in this article.

Valve varieties

There are numerous factors that must be taken into account when selecting the correct control-valve solution for an industrial process. There are several different control-valve types on the market, available from various manufacturers, each of which provides different valve designs with their own suitable applications. Selecting the wrong type of design can jeopardize the lifecycle of the control valve and increase the need for maintenance and spare parts. More importantly, it will have a major impact on plant operations, efficiency and costs.

Control valves can be categorized into two groups based on valve-stem movement — either rotary (quarter-turn) or linear (rising-stem) types are available. Typical rotary and linear valves are shown in Figures 3 and 4, respectively. The body shapes of these valve types differ greatly, along with their open-close behavior mechanisms. In a quarter-turn valve, the actuator rotates the valve stem and closing member to open or close the valve. In the linear type of valve, the actuator either lifts or pushes downward toward the valve stem and closing member to open or close the valve. The most common types of rotary control valves are eccentric rotary-plug valves, V-port segment valves, eccentric-disc and trunnion-mounted control ball valves. Figure 5 shows an internal view of an eccentric rotary-plug valve. The most common types of linear control valves are unbalanced and balanced globe valves. Figure 6 shows some of the internal components of a linear globe valve.

Both linear and rotary types of valves have special properties that make them favored in specific application areas. For example, high-pressure applications typically

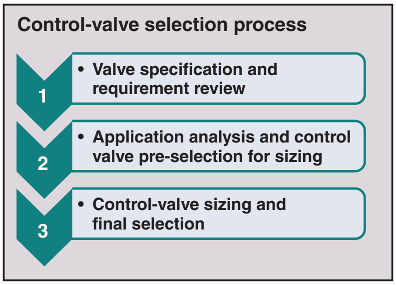

FIGURE 7. The selection process for control valves involves reviewing datasheet specifications and analyzing the specific applications and sizing procedures for final selection

favor the linear type of valve design. For valves of the same size, linear valves are typically more cost-effective in high-pressure applications than rotary valves. In high-pressure applications, the valve must be able to handle the large dynamic forces that are caused by the high differential pressure. With rotary valves, this means that the valve must be equipped with a larger-diameter stem or use high-strength stem material, both of which increase costs. However, due to the higher flow capacity, sometimes smaller-sized rotary valves can be used, which can favor a rotary design and also make them attractive from a cost point of view.

On the other hand, rotary valve types are the preferred option for many other applications, because they possess better capabilities with fluids that contain impurities, such as particles or wax. Rotary valves are not as sensitive to impurities as other valve types, due to a "self-cleaning" seat construction, making them less likely to experience plugging. Linear valves, due to the curves of their inherent structure, are more susceptible to wear and damage from impurities. Rotary control valves are also desirable in applications where there is a risk of coke buildup, as well as applications where lower emissions and more reliable gland-packing sealing are required.

The cost of different valve types can vary greatly depending on manufacturing specifications, design differences and material selection.

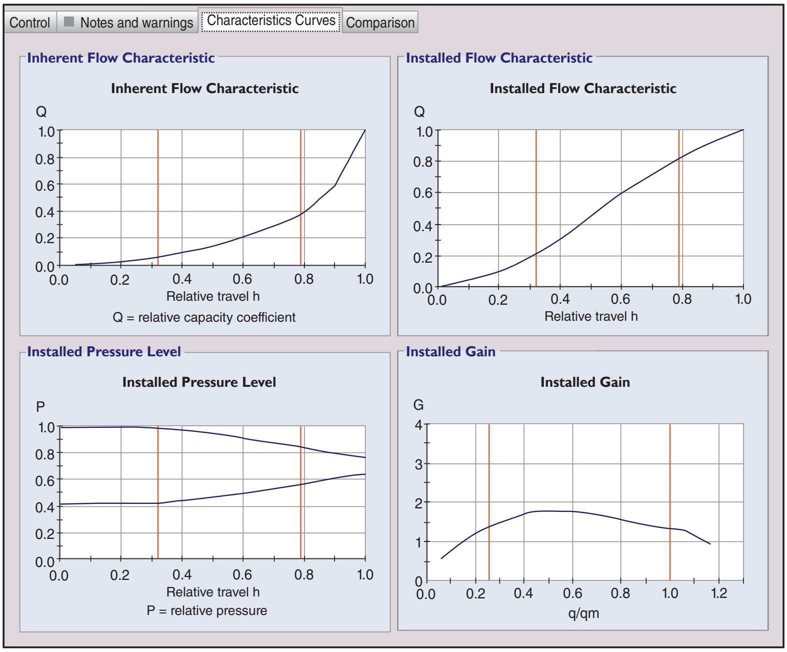

FIGURE 8. A sizing and selection system enables correct control-valve selection based on application requirements. The system also helps users analyze the valve's installed behavior in the process and compare different valve models to find the optimal control-valve solution for a specific application

Sometimes a rotary valve is more economical than a linear valve, and vice versa, proving that an understanding of valve sizing and selection requirements is extremely important for process economics. Less maintenance will always be required when the correct valve is placed into service.

Selection steps

Once the basic process requirements are known, the more detailed evaluation for equipment selection can begin. Figure 7 illustrates the phases of valve selection that engineers should follow. Typically, the control-valve selection process begins with the end-user specification review. During this phase, end-user requirements need to be clarified in detail, including information about necessary certifications and approvals. Since not every control valve is available with all of the required certifications and approvals (specifically, those regarding emissions, safety-integrity levels [SIL] and fire safety), these must be taken into account during the final valve-selection activities.

The next step in the selection process is the application analysis, where information from process datasheets is reviewed in detail. This phase gives important information about the application's pressure and temperature levels, along with detailed flow-medium information. Valve manufacturers have their own knowledge and reference databases, which help with the valve pre-selection process for different applications. However, the final valve and material selection should always be based on the real process and flow-medium information, always taking into account possible particles in the fluid. After the detailed application analysis based on process datasheets, the valve type can be pre-selected for preliminary sizing purposes.

Depending on the end-use application, there may be many control valve designs and options that can be successfully utilized. As an example, in clean, general-service applications, either rotary or linear control valves can be deployed. Ec-

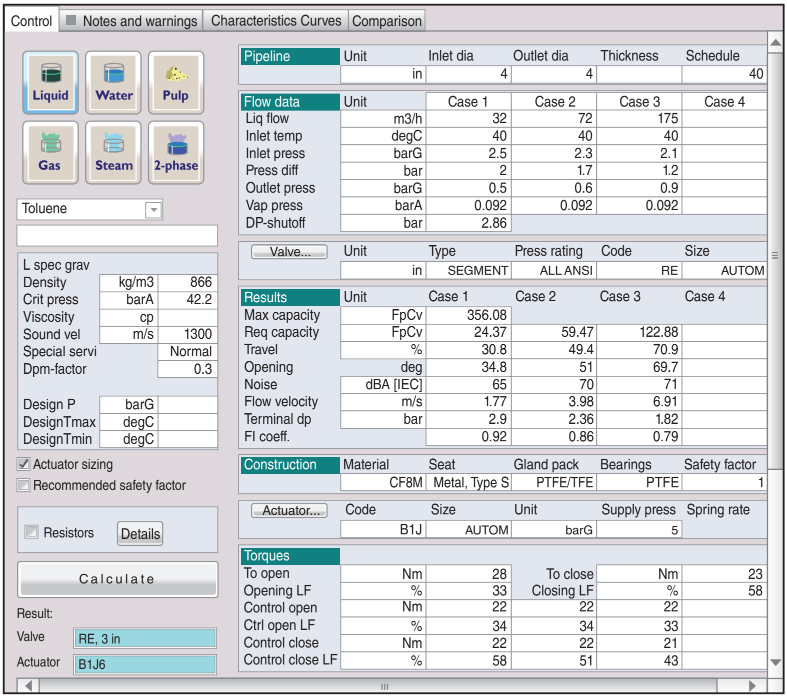

FIGURE 9. Software used for the sizing and selection of valves requires accurate input data based on actual process operations

centric rotary-plug valves, V-port segment valves or globe valves (either balanced or unbalanced) are the most common valve types for these sorts of common applications. However, for specialized or more demanding applications, the number of suitable control-valve designs decreases — more detailed valve-damage prediction models must be obtained before a proper valve type can be confidently selected. Damage predictions are typically based on noise prediction, cavitation detection and velocity calculations. Possible noise or cavitation problems can usually be avoided by selecting suitable low-noise or anti-cavitation trims for valves. With linear valves, these special trims are typically available only for clean-duty applications, whereas rotary valves with low-noise trims can be used even if the flow medium contains some particulate matter, dirt or fibers. The presence of particulate matter in the flow medium places even more emphasis on correct control-valve sizing and valve material selection, because possible erosion problems can occur.

Erosion problems are exacerbated by not only the presence of impurities, but also by the flow velocity and form of the valve body. Linear valve types are more susceptible to erosion because their curvy shape allows for more contact between particulate matter and valve walls. In situations where erosion may cause issues, valve constructions that reduce flow velocity and particulate contact with valve surfaces are preferred.

The actual control-valve sizing should be finalized with valve-sizing software based on international sizing standards. There are some commercially available software options on the market, and some valve manufacturers have their own sizing tools for this purpose. Figure 8 shows some valve-performance results from valve-sizing software. Users can analyze such results to aid in purchasing and installation decisions.

Many sizing tools give the simulation's calculation results with the valve's inherent flow capacity (Cv) curve, which shows the valve's installed capacity at a constant pressure drop. However, in actual operations, the pressure drop is of course, not constant, meaning that further details may be required from simulation tools for optimal valve selection. Therefore, the most effective sizing tools are simultaneously able to calculate the valve's installed characteristics while also simulating the valve's installed behavior in the specific process. This allows for better valve selection, since the basis is in actual observed process conditions. Simulation results are based on the selected valve's inherent characteristics and modeling of the specific process behavior. The control valve's installed characteristic and performance analysis provides essential information for correct valve size and trim selection for the application, essentially informing users of how a valve really behaves in a given application. It also enables a performance comparison of different control-valve models and options, giving the user a clear image of the capabilities of different valve types prior to final decision-making.

It is important to keep in mind that flow-modeling calculations and simulations are only as accurate as the available process data. Figure 9 shows example process-data inputs to a valve-sizing software system. When selecting and sizing a control valve, it is highly recommended to take all of the process-load conditions into account as accurately as possible and make sure that the selected control valve can actually handle all of the different process conditions that the application requires.

For instance, sometimes the control valve must handle a very wide range of flowrates. Small flowrates, which may occur during a process-startup situation, must be controlled with the same reliability and precision as the much higher flowrates seen during normal process operation. For this kind of service, high-range-capable rotary control valves are generally the best and the most economical solution, due to their higher maximum flow capacity and inherent flow characteristics. The valves possess the capability for a wider minimum-maximum control range. This high-range capability also provides flexibility against possible future process-value changes. With linear-type valves, large changes in flowrate will typically also require changes in a valve's internal parts.

After the final sizing and selection steps, it is vital to re-examine the application's specifications and make sure that the selected valve completely fulfills the process requirements. Once again, it remains crucial to ensure that all of the needed emissions and fire-safety certifications are available for the selected valve type.

Intelligent valve technology

Another factor that purchasers must consider when selecting valves is the controllers' capabilities, from a technology standpoint. Most new control valves are equipped with digital or intelligent valve controllers instead of traditional analog positioners. Digital control-valve positioners provide digital communications via a microprocessor utilizing industrial communication protocols, such as Hart, Foundation Fieldbus or Profibus. In addition to digital capabilities, intelligent valve controllers also have embedded valve diagnostics and online monitoring capabilities, which can be used to monitor the valve's current status and predict possible upcoming failures and maintenance needs.

This provides additional safety for the operations and maintenance staff, as well as adding layers of protection to the process environment. Instead of sudden reactive maintenance, intelligent condition-monitoring capabilities enable the adoption of a more systematic approach. Possible maintenance needs can be targeted before they are able to affect the performance of the process, allowing for more comprehensive maintenance planning. Valves that need maintenance can be clearly identified. Then a provision of spare parts, the correct tools and even the service work itself can be planned well in advance, thereby avoiding extra hassle and inherent risks associated with unplanned shutdowns.

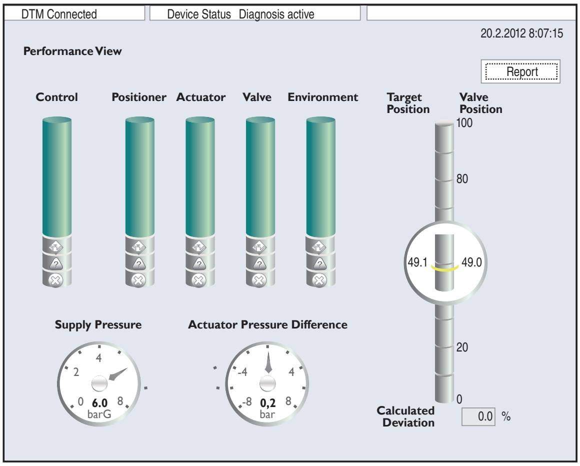

FIGURE 10. This valve-manager system graphically displays a control valve's performance and the online status of each valve component. The report function gives detailed explanations of the performance status and further guidelines for recommended actions

Clearly, this approach requires some monetary investment — the purchase of intelligent valve controllers and condition-monitoring tools must be considered with the overall lifetime cost, while still taking into account the possible savings resulting from a more systematic maintenance strategy.

Simultaneously, these features can be used to improve process efficiency and reduce production costs. Failures or malfunctions can be detected via device diagnostics before they cause problems in the process and in the plant's production. With intelligent devices and a condition-monitoring system, not only can one observe the valve's diagnostic history, current status and performance, but also predict its future. Figure 10 shows an output screen of a valve-management software program.

The hallmarks of a high-performance control-valve system are the construction of the valve itself and the system's intelligent capabilities. The valve should be frictionless and backlash-free and the intelligent controller should provide precise position control. The presence of non-leakage, live-loaded valve packing in the valves effectively eliminates the need for gland-packing maintenance, while the intelligent-control capabilities enable true predictive maintenance through online diagnostics.

Final thoughts

Control valves are the cornerstones of a modern process-industry control system. They work continuously to compensate for process disturbances and follow changes in control setpoints to ensure process yield and stability. When the reliability of a control valve in a specific application is considered, it is important to know all of the factors that can affect the valve's performance and lifecycle. A reliable, long-lasting control-valve solution requires that the valve is correctly selected and sized based on the application's process requirements and actual operating conditions. Overall, a good control valve should always be selected with reliability and accuracy in mind. ■

Edited by Mary Page Bailey

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Project Optimization Through Engineering

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Follow these practical recommendations to reduce capital outlay and operating costs, deliver shorter schedules and improve design quality

In the face of intense market pressures, companies are increasingly requiring their engineering organizations to complete capital projects more quickly, while spending less capital and creating systems that cost less to operate over the long run. They are also asked to do this with fewer engineers. While this "do more with less" philosophy may not seem feasible to some, it is possible when the following conditions are met[1]:

- The project team, before work begins, sets clear, measurable objectives using input from both business and technical managers. Getting the management to fully engage and provide quality input for objective-setting can be difficult. A proven process for setting objectives and implementing techniques for getting high-quality management input can be found in [*1*].
- The project team creates and studies a comprehensive list of design options early on, and continues doing so throughout the life of the project. This will help create a strong economic focus. Experience has shown that when leaders maintain such focus throughout the project, project teams can reduce capital costs by 5–10% and keep scope changes to no more than 1% of capital
- The project team develops a project schedule and plan at the start of the project, based upon firm decisions made early in the project. At the start of each design phase, the team updates its schedule and plan. Table 1 provides details for supporting schedule development throughout the key phases of most capital-intensive projects
- Management staffs the project with an appropriate number of experienced engineers from the key disciplines. The level of experience depends upon the size and complexity of the project, with larger, more-complex projects requiring more expertise

As reported by the Construction Industry Institute (CII) Study, SD 105 [*2*], these requirements have a statistically significant correlation with reduced costs, shorter schedules and better design quality. The best-organized projects beat their targets. According to the CII, for such projects, average capital costs were 4% lower than expected, and schedules were 13% shorter. Compared to poorly organized projects, well-executed projects performed much better, enjoying capital costs that were 20% lower and schedules that were almost 40% shorter [*3*].

The last three bullets on the list above are interrelated. Because they result in design decisions, option studies are the pivotal item; the other two items are supportive and necessary if the team is to execute the option study well. The project schedule integrates option list development and option study with the other work in the project. For the team to create a comprehensive and thorough list of design options, it must be staffed with the right level of experienced engineers.

This article discusses the creation and analysis of design options. These include selection and sequencing of process operations on the flowsheet, unit- operation selection, and spatial and layout arrangements. Specifically, this article addresses the following topics:

- Why create thorough and comprehensive option lists?
- What options are studied and when are they studied?
- Option-creation tools
- Analysis and selection of options, both technical and economic

Why create thorough and comprehensive option lists? The cost structure of a project is set by the decisions made in the early design phases — during process development, feasibility engineering, conceptual engineering and project definition. Accordingly, the design team, as it makes decisions, needs to have a strong economic focus from the start. Decisions made early in a project have long-lasting, often unchangeable effects. For example, selecting a site in an area that has limited labor availability and a poor labor climate will have long-lasting effects on labor costs and productivity.

Conducting an early study of the options can help to reduce engineering staffing and costs.Options are studied early using "study-level"[2]

1. Paraphrased from: "Construction Industry Institute Study," SD 105: Organize for Pre-Project Planning (Section 2.3.1), and Select Alternatives (Section 2.3.2); pp. 12–14.

2. Experience has shown one can normally use these lower-accuracy methods to compare options and make high-quality decisions.

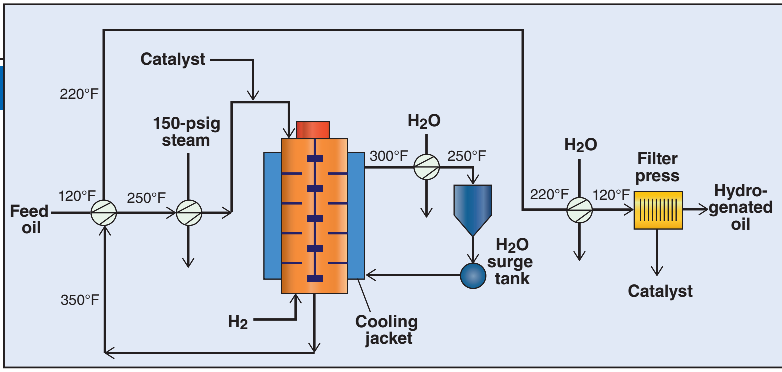

FIGURE 1. In most projects, the engineering team misses an opportunity by not developing an option list that is as comprehensive as possible, and settling quickly instead, on a shorter list of feasible options. An example, using the hydrogenation process for a new product shown here, is discussed in the text

techniques, which require less effort and cost compared to more-detailed methods. If a project team were to do the same studies later in the project, it would require greater effort and cost as it would include more people and details that are not necessarily needed for proper studies. Additionally, earlier study creates a more solid-design foundation and enables the team to be more focused and more efficient in the later phases of the project. When studies are carried out later in a project, changes are often required in some other part of the design. The later the changes are made in a design, the more they increase costs and lengthen the schedule.

There are other compelling reasons to increase the focus on options Heath and Heath [*3*] summarized the psychological research on decision making quality. The research shows that quality in decision making is improved when decision makers do the following:

- Widen the scope and number of options they consider
- Reality-test their option-limiting assumptions
- Step back from their decisions, consider more than their favorite solutions, and look at the problem "through the eyes of others"
- Evaluate what might be wrong with their decisions

Applying these recommendations to a project will result in an increased focus on identifying relevant options, leading to a more comprehensive and thorough list of options than is typical today. The process of creating a more comprehensive list will cause the team to challenge their restrictive boundaries and will take their thinking well beyond their favorite solutions.

Few projects develop as comprehensive a list as is possible. Being good problem solvers, engineers have the tendency and ability to converge quickly to an answer. To illustrate, consider an engineer who is asked to develop a hydrogenation process for a new product. He or she might quickly draw the flowsheet that is shown in Figure 1 (which shows a workable design). Once the flowsheet is drawn, the search for other options — ones that might be technically or economically better — is largely over.

However, having a more thorough and comprehensive list of options increases the number of alternatives that the design team will study and increases the probability of selecting higher quality, more elegant design solutions. In turn, that will improve project economics. Secondarily, the team will run more efficiently and experience fewer disruptions. As a result, cost and schedule control will become simpler and more effective.

A properly staffed project team is a prerequisite for the creation of a thorough list. If a team does not have members with experience that matches the size and complexity of the project, a comprehensive set of design options will be not be properly developed. When the team has experience that matches the project, the group is able to envision different design possibilities, and that results in a better and more complete option list. A well-staffed team will have engineers with process engineering, civil or architectural engineering, electrical and controls experience and so on. It will also include members with manufacturing and construction expertise.

A number of years ago, a Fortune 100 company had to take remedial action when designing a large (more than $50 million) plant expansion. The project involved several new, complex technologies. While the plant eventually started up and operated successfully, the capital cost was more than twice what was expected and the startup was delayed by about a year. Although there were many reasons for this, the most significant was inadequate staffing. The team was well staffed with process members, but the ancillary disciplines — warehousing, materials handling, environmental and construction — were not. As a result, the warehousing, the materials-handling capabilities and the sewage-treatment scope were poorly defined. Later in the project, when the team realized this, these facilities had to be designed on a rush basis. Since there was no time in the schedule for this work, the team had to select options quickly and design them in haste. The added work delayed the schedule, and the new designs caused other scope changes, which further increased costs and delayed startup. On top of that, the development of the original schedule had received little input from construction. Consequently, during construction planning later in the project, the team realized the plant site was so congested that the original schedule was impossible to execute.

When creating option lists, the team needs to consider the entire design, including the following elements:

- *Process, piping, controls, civil and architectural, utilities and so on.* It is important to work out these aspects of the project early, to ensure optimal execution
- *Layout and spatial designs.* These involve deciding where to locate equipment, offices, maintenance shops, warehouses and so on; and where to route piping, ductwork, utility and electrical chases or racks. The study of spatial options lets the team optimize the use of plant space

TABLE 1. PROJECT PHASES AND DESIGN PROGRESSION

		Process-development phase	Feasibility phase, FEL-1 (FEL = Front-End Loading)	Conceptual phase, FEL-2	Definition phase, FEL-3	Design phase
Purpose of each phase		To define the key process steps and operating conditions, raw- and packaging-material specifications and process design data (Such information helps to define technical feasibility)	To develop a workable plan and to determine whether or not proposals are economically feasible	To develop the major features of the design for the selected, feasible option	To complete the design in enough detail so that construction drawings and instructions can be efficiently developed	To create construction drawings and instructions so the plant can be built correctly
Design development	**Engineering plan and schedule**	A. Detailed process-development schedule	A. Detailed engineering schedule for FEL-1 and 2 phases; preliminary engineering and construction schedule showing time allocation	A. Develop detailed engineering schedule for the FEL-3 phase, including an updated preliminary engingeering-and-construction schedule showing time allocations	A. Develop a detailed engineering schedule for the design, and an updated preliminary construction schedule that shows time allocations and major milestones	A. Create the first draft of the detailed construction schedule
	Flowsheet/ process	B. Block-flow diagram;pilot-plant-based material and energy balances	B. Process flow diagram (75% complete); preliminary material and energy balances	B. Prepare final issue of the process flow diagram and bring material and energy balances to ~95% complete	B. Develop P&IDs to ~95+% complete; Complete material and energy balances	Achieve 100% engineering completion on all of these items
				C. Write first or second draft of the process description	C. Complete the process descriptions; finalize design bases to ~95+% complete	
	Equipment (including utilities and electrical)		D. Preliminary selection of all major and some minor equipment	D. Create major equipment and motor list, and plan for the purchase of equipment with very long lead times	D. Develop equipment and motor specificiations to ~95+% complete, and purchase remaining equipment with long lead times	
	Electrical/ controls		E. First draft of control strategy	E. Create the control strategy, write first draft of power-distribution single-line diagrams, and create first cut of logic diagrams	E. Bring single-line diagrams and logic diagrams to ~95+% complete	
	Health, safety, environmental (HSE)	F. Identify potential HSE hazards	F. Preliminary HSE risk assessmet plus a prevention and mitigation plan for major hazards	F. Create HAZOP analysis for all major hazards, plus preliminary designs for all HSE items	F. Complete the HAZOP analysis and final HSE designs	
	Other		G. Preliminary building and utility requirements	G. Update the building and utility requirements	G. Identify final building and utility requirements	
	Layout/ modeling		H. Preliminary site selectin and layout	H. Bring site selection and layout to ~90% complete	H. Complete the site layout	
			I. Study models and preliminary equipment layouts	I. Further develop study models and preliminary equipment layouts	I. Finalize construction models and equipment layouts to ~95+% complete	
	Estimates	J. Use order-of-magnitude estimates for preliminary capital estimates (accuracy is ±40–100%); use study estimates for option analysis (±30–50%)	J. Use preliminary control estimates for authorizing further work (accuracy is ± 25–30); study estimates for option analysis (±30–50%)	J. Use preliminary control estimates for authorizing a full project start (accuracy is ±20–25%); use study estimates for option analysis (±30–50%)	J. Use definitive estimates for appropriation cost control (accuracy is ±15–20%); use study estimates for option analysis (±30–50%)	J. Use detailed estimates for construction cost control (accuracy is ±10%)
Example options to be studied		• Make or buy the product? • Sequencing of process steps • Unit operation studies • Recycle or purge needs • Scaleup criteria • Technical feasibility of different raw and packaging materials • Key operating conditions	• What technologies or processes are economically feasible? • Batch versus continuous operation? • Optimize the process around the dominant or pivotal process • Materials of construction options • What is the energy-recovery plan? • Unit operation options • Number and location of plant sites • Site and major equipment layout	• Optimize the process around the dominant or pivotal process • Optimize the major pieces of equipment: operating conditions versus equipment size • Materials of construction options • Site layout and equipment layout options • HSE hazard elimination and mitigation options • Major constructability and maintainability options	• Optimize the minor pieces of equipment, piping, insulation and so on • More detailed constructability and maintainability options	• Optimize the constructability and maintainability of the plant

- *Plant operation, maintenance and construction*. Space has to be allocated for construction laydown areas

By themselves, the higher quality lists will result in better designs, better technology and lower capital and production costs.

What options are studied and when are they studied? A design team will study options throughout the life of a project, using the project schedule to organize its work. A good schedule provides assurance that decisions build upon each other as the design progresses. Referring to Table 1, note how the health, safety and environmental (HSE) scope develops. In the process-development phase, HSE simply involves identifying potential hazards. Next, during feasibility engineering, the engineers go into greater depth, completing a risk assessment plus a prevention-and-mitigation plan for the major hazards. During the conceptual phase, the team begins HAZOP studies and carries out preliminary designs for such things as systems to treat sewage and gaseous emissions. Discussed next are examples of the types of studies that should be carried out during the following project phases:

During process development. During process development, the design team would consider broad topics such as the following:

- What should the major steps in a process be and how should they be sequenced?
- Considering the different raw material types and grades, which are best for the process?
- Recycle or purge streams — should they be used? Should recycle streams be purified prior to recycle? Should purge streams be treated or reclaimed?

During feasibility engineering. During this phase, the project team develops a design for a workable plan to learn whether their proposal is economically feasible. While the studies are more focused than those carried out during process development, the team will still study options that are rather broad, such as the following:

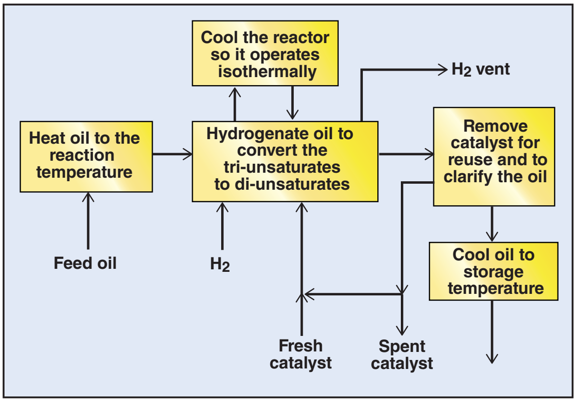

FIGURE 2. Shown here is the technical function flowsheet (TFF) for the hydrogenation process shown in Figure 1. The TFF is a handy tool that offers a different way to approach flowsheet development, and supports the creation of a broader list of engineering options to be considered early in the lifecycle of a project (With permission from CRC Press)

- Which is the best unit operation for each process step?
- How many sites are economically optimal and where should they be located? Should health, safety and environmental considerations be critical siting factors? Should an existing plant or process be modified or a new one built?
- What is a reasonable site layout? To develop good layouts, the team will need to visualize the plant layout. (The use of 3D conceptual software, which is designed specifically for the visualization of options, will assist the team with layout studies.)

During conceptual engineering. At this stage, the options become more narrow and the team should be focused on the following activities:

- Consider options for heat recovery and optimize the heat-recovery and utility systems
- Study the tradeoffs among the reactor or dominant process, the recycle and purge systems, the separation systems and the heat-recovery system. For example, one of the tradeoffs in the process shown in Figure 1 involves the reactor, the filter and catalyst concentration. Specifically, if the catalyst concentration is increased, catalyst cost increases, reactor size and cost decrease, and the filter size and cost increase. This is a classic optimization situation where one can calculate total system costs (in terms of catalyst, reactor and filter) for a variety of catalyst concentrations. From those calculations, one can then find the minimum system cost.
- Study different preliminary site or plant and major equipment layouts. These types of options require the ability of the team to visualize the arrangement of equipment, piping and more, in three dimensions (3D). Again, 3D conceptual software will help the team to visualize many options

During the definition phase. At this point, the team focuses their efforts more, developing the design in sufficient detail so that construction drawings and instructions can be efficiently produced. Studies would include the following:

- Select the type of heat exchanger for each service — U-tube, fixed-tube-sheet, plate-and-frame or other
- Decide whether the process, or parts of it, will be assembled from shop-fabricated modules
- Locate all the process units, the majority of the equipment and optimize major pipe and conduit rack sizes and routing

Over the years, we have heard many reasons not to study a larger array of options. The more common reasons are the following:

- There is not enough time
- It costs too much to study all those options
- There are not enough people to carry out the studies
- We already have a workable option, one we have used for years

When one reflects upon the conclusions made in [4], it is easy to conclude that these excuses are

TABLE 2. TECHNICAL FUNCTION DEFINITION FOR OIL HYDROGENATION, 2ND ISSUE				
Function	**Purpose**	**Quantification**	**Basis**	**Unit operation type**
Feed oil	To provide oil for the reaction	• 115–125°F	• This is the storage temperature of the oil • See raw material specifications	
Oil heating	To bring the oil to reaction temperature	• 345–355°F	• See pilot plant report	TBD
Reactor	To hydrogenate the fatty acid chains to di-unsaturated chains	• Oil characteristics: - 99% conversion of tri-unsaturates to di-unsaturates - Limit hydrogenation of the di-unsaturate and oleic chains to < 1 and < 0.5% • Reaction conditions: - Reaction endpoint: Iodine value of 114 (unitless) - Temperature: 345–355°F; Pressure: 30– 40 psig; H_2: Up to 20% excess; Catalyst: < 0.5 wt.% - The reaction rate is directly proportional to catalyst concentration	• Testing has shown this type of oil is preferred by 70% of consumers for health reasons • See pilot plant report for reaction conditions and reaction and process data	TBD
Reactor cooling	To operate the reactor isothermally	• See reaction conditions	See pilot plant report	TBD
H_2 addition	To provide H_2 for the hydrogenation reaction at the reaction pressure	• See reaction conditions • Because of impurities in the H_2 feed stream, it is more economical to vent rather than recycle it	• See raw material specifications • See pilot plant report • See H_2-vent study	TBD
Catalyst addition	To catalyze the reaction	• Catalyst may be reused six times	• See raw material specifications • See pilot plant report	TBD
Oil-catalyst separation	To remove catalyst from the oil so that: • The oil is clear • The catalyst can be reused	• Achieve oil clarity so that <3 ppm of catalyst is left in the oil	• Oil is cloudy at concentrations > 3 ppm and this reduces consumer preference to <10% (compared to customers selecting other products)	TBD
Oil cooling	To bring the oil to storage temperature	• 115–125°F	• Oil flavor will degrade at higher temperatures	TBD

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most often shortsighted and result in poorer decisions, poorer design quality, higher costs and longer schedules.

Another issue is that engineers often become "stuck" after identifying the first few options. They do not know what else to consider. This speaks to the lack of knowledge of option-development tools and technology. Useful option-development tools are addressed next.

Option-creation tools

Today, a number of tools are available to facilitate and simplify the creation of a complete option list. Four are discussed here — technical function flowsheets (TFFs), unit operation guides, question lists and 3D conceptual-design software.

Technical function flowsheets (TFF). TFF offer a different way to approach the development of a flowsheet. Their purpose is to set the stage for option-list creation by promoting divergence during one of the most creative times in the life-cycle of a project.

A TFF shows each process step or technical function in its own block, arranges the steps or blocks in their proper order and connects them with process flow streams. Figure 2 shows the TFF for the hydrogenation process shown in Figure 1. Comparing Figure 2 to Figure 1, one can see that the TFF leaves the way open to explore options for each of the technical functions. Specifically, the reaction step is shown as "hydrogenate oil …" It is not identified as a "batch reactor" or a "multistage, stirred-column reactor." By leaving unit operation and equipment choices open for later study, the TFF enables the creation of a more comprehensive option list. For more on how to create a TFF, see Ref. 5.

Material and energy balances and a technical function definition (TFD) provide backup details for the TFF. The TFD specifies operating conditions and explains the basis for each. Table 2 is the issue of the TFD that supplements the flowsheet in Figure 2.

Unit operation guides. The unit operation guides list the common unit operations. One uses them when selecting unit operations for the technical functions on a TFF. There are eight guides, one each for: Blending-mixing, drying, heat transfer, mass transfer, material transport, mechanical separation, reactions and size modification [*6*]. Table 3 — the heat-transfer guide — shows how the guides are arranged. Across the top are columns for the different process-stream phases. In the columns are lists of applicable unit operations. The references used to compile the guide are listed at the bottom of the page.

Question lists. The intent of the question lists is to encourage team members to think more deeply about the process in order to identify additional alternatives. During process development, the questions are broad in nature and relate to the general process and the interactions of one part of the process with another. The complete list of questions can be found in Ref. 7. A few examples are provided here:

- Should the process be batch or continuous?
- What different grades or sources of raw materials are available? What effects do these have on human or environmental safety and on process operation and costs?

- How can one manipulate the unit operation to control the final product attributes or the condition of its output stream?
- How can the tradeoffs be optimized among the reactor or dominant process, the recycle or purge streams, the separation systems, and the heat-recovery system? Should there be one or multiple units? Should there be surge between the unit operations; how much? What is the heat recovery plan? How should the heat-recovery system and the utilities be optimized?

Spatial options and 3D conceptual software. During feasibility and conceptual engineering, the project team will begin to study layout options and work toward finding an optimal layout. Again, the team ought to think about the complete scope of the project, including plant operation, maintenance, safety and construction. When a project has a large amount of piping, electrical or ducting work, the team must allocate or reserve space for these items in the layout. It may also need to do some preliminary design work and develop material estimates for structural steel, piping, cable trays, and ductwork, to analyze different options. The team should also consider the possibility of modularizing all or part of the plant. For a discussion of the benefits of modular construction and provides guidance on how to decide whether or not to use it, see [*8*] and [7], respectively.

In the past, there were only limited and cumbersome tools for carrying out early-phase layout studies. Typically, these were done using Styrofoam blocks, 2D cutouts or 2D CAD drawings. The design team would move the blocks or cutouts around to get a rough feel for the different options. These methods were only qualitative in nature — one could not use the findings to assess the economics of one option versus another. Some project teams use 3D computer-aided drawing or design (CAD) systems, but these are detailed design tools and tend to be difficult, awkward, and expensive to use in conceptual studies.

FIGURE 3. Engineering teams should consider using software to generate images in 3D format, since this can help the team to visualize the complete plant layout from laydown areas and roads to the equipment, structures, piping, electrical locations and so on

Today there are several 3D conceptual design tools that are ideal for developing and evaluating site, process, equipment, piping, and transportable module layout options. When considering the different 3D systems, look for those having the following features:

- *3D formats.* The software should provide a 3D format that lets the user easily visualize the complete plant layout from laydown areas and roads to the equipment, structures, piping, electrical locations and so on. Figure 3 shows an example site layout that is generated by one of the conceptual software products
- *Built-in knowledge bases.* The better conceptual software packages will have built-in rules to support proper equipment spacing and to check for interferences. They also support automated pipe routing. The software should be able to let the users input their own spacing and routing rules. These packages will also optimize pipe routing by considering lengths and fittings and giving routing priority to the more expensive piping
- *Built-in calculation routines.* To assist the team with the analysis of different spatial options, some software includes automated calculation of key items, such as pressure drop, pipe sizing, pipe stress and structural-member sizing
- *Bill-of-materials capabilities.* The routing and calculation subroutines are also used to develop the bills of materials. This capability lets the user estimate costs, economically analyze and compare different layout options
- *Layout option capability.* A package that allows the user to easily generate different layout options by simply moving equipment or piping is invaluable. Once something is moved, the built-in knowledge bases and calculation routines take over, making any needed adjustments. For example, if an engineer locates a piece of equipment too close to another, the program, using its spacing rules, would automatically shift the offending equipment to meet the required spacing
- *Transportable modules.* For teams considering transportable modules, having a software package with built-in module-design rules is a definite plus. If the design rules include allowable sizes and weight restrictions for transporta-

TABLE 3. HEAT-TRANSFER UNIT OPERATION GUIDE		
Gas heating and cooling	**Liquid heating and cooling**	**Solid heating and cooling**

Direct contact (of the hot and cold streams)
• Cooling or condensing operations:
  • Spray chambers
  • Packed column
  • Tray columns
  • Pipeline contactors
• Heating systems
 	
Indirect contact
• Shell-and-tube heat exchangers:
  • U-tube exchangers
  • Fixed-tube-sheet exchangers
  • Floating-head exchangers
• Double-pipe heat exchangers
• Air-cooled heat exchangers
• Spiral-heat exchangers
• Process furnaces
	Direct contact
	• Steam injector
	
	Indirect contact
	• Shell-and-tube heat exchangers:
	  • U-tube exchangers
	  • Fixed-tube-sheet exchangers
	  • Floating-head exchangers
	• Reboilers:
	  • Kettle
	  • Thermosiphon
	  • Forced flow
	• Double-pipe heat exchangers
	• Air-cooled heat exchangers
	• Plate heat exchangers
	• Spiral heat exchangers
	• Scraped-surface heat exchangers
	• Thermal fluid heaters
	• Process furnaces
	• Vessel heat-exchange options
	  • Tank coils
	  • Bayonet heater
	  • Vessel jacket
	
	Evaporators
	• Natural-circulation evaporators
	  • Short-tube or calandria units (basket)
	  • Long-tube units (vertical)
	  • Falling-film units
	  • Rising-film units
	• Forced-circulation evaporators
	  • Vertical tube
	  • Horizontal tube
	  • Agitated calandria
	  • Agitated thin film
	  • Horizontal spray film
	  • Plate type
	• Batch pan evaporator
		Particles or divided solids
		• Direct contact (of the hot and cold streams)
		  • Rotating-drum units
		    • Plain-cylinder units
		    • Flighted-cylinder units
		  • Fluid-bed units
		  • Vibrating-conveyor units
		  • Belt conveyor system
		  • Spouted-bed units
		  • Pneumatic conveyor
		
		Indirect-contact
		  • Rotating drum
		    • Tubed-shell units
		    • Plain-cylinder units
		    • Flighted-cylinder units
		    • Deep-finned units
		  • Spiral conveyors
		    • Jacketed, solid-flight units
		    • Large- spiral, hollow-flight units
		    • Small-spiral, large-shaft units
		    • Rotating-paddle units
		
		Sheeted solids
		• Cylinder heat-transfer unit
		
		Solidification of melted solids
		• Table-type
		• Agitated-pan units
		• Belt-type units
		• Rotating-shelf units
		• Rotating-drum units
		• Vibratory-type (caster) units
		
		Fusion/melting of solids
		• Vertical agitated kettle
		  • Screw conveyor
		  • Ribbon blender
		• Horizontal tank type
		• Mill type
		  • Paddle or screw mixers
		  • Banbury mixers
		  • Multiple-roll

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tion, module size, lifting and moving requirements, the software can automatically optimize module size and weight

- *Importing and exporting data.* Many of a project team's calculations are done within Microsoft Excel, so a good software package will provide for streamlined data import and export to and from Excel
- *Data continuity.* Maintaining data continuity from one project phase to another is important so that a project team does not have to enter the same data into multiple software systems. A high-quality system will be able to easily interface with and transport data to other important design tools such as: process simulation software, design software and estimating tools

Analysis, selection of options

The project team will first analyze options from a technical standpoint. This typically eliminates most of the options. Commonly, more than one option is feasible and will remain on the list for further consideration. When that is the case, the team can use economics to choose the best of the technically feasible options. It does this by posing and answering the following two questions:

- Is it better to spend more capital and have lower production costs?
- Is it better to spend less capital and have higher production costs?

The answers to these questions help the team to identify the economic balance point between capital and production costs.

To illustrate, assume there are

two technically feasible options for removing solid catalyst from the process stream shown in Figure 2. The first is a plate-and-frame filter press. The press requires little capital, but has to be manually cleaned, resulting in significant labor costs. The second option is a self-cleaning, enclosed filter. The enclosed filter requires more capital, but it has no cost associated with cleaning. In this case, the engineer has to decide whether elimination of the labor expense to clean the plate-and-frame filter will justify investing more capital for the enclosed filter.

In an analysis such as this, one first develops rough designs for the major equipment in each option. Using those, the engineer estimates the capital cost and production costs for both options. When determining production costs, one has to consider only the costs that are different for the options. For example, in these two filtration options, plant overhead charges would be the same for each option and would not be considered or estimated. Labor costs, however, would be different and would be estimated.

With estimates of the different options in hand, one next calculates either the net present value (NPV) or the annual cost (AC) for each option and selects the one having the best economics (the authors suggest using your company's ROI or hurdle rate criterion as the discount rate). Since this kind of analysis only considers capital- and production-cost expenditures, the NPVs and ACs for both options will be negative. Thus, when selecting the most economic options, one would select the option having the lowest costs or the "least negative" NPV or AC.

A few general comments are in order. For most analyses, study-grade estimating techniques are sufficient. For studies carried out during process development, and during feasibility and conceptual engineering, they are typically the only methods available because so few design details are available. Ref. 9 details study techniques for estimating both capital and production costs. For spatial options and some project-definition options, more detailed estimating methods are needed. Lastly, while NPV and AC are the preferred and easiest-to-use economic comparison methods, one should also use whatever his or her company requires when carrying out economic analyses.

Closing thoughts

The CII Study, SD 105, found that improved project cost and schedule performance results improve when project teams set appropriate project objectives and carry out the following tasks:

- Create and study a comprehensive list of design options early in a project, which will also produce a strong economic focus for the project
- Develop a project schedule at the start of the project, based upon making decisions early in the project; the project schedule integrates option identification and study, and the resulting design decisions, with the other project activities
- Staffing the project with an appropriate number of experienced engineers from the key disciplines. good staffing is a precursor to creating a complete and thorough option list — and to making the best design decisions

Of these, option creation and study are the pivotal activities, and the other two are supportive activities.

Option analysis is straightforward. First, the team carries out a technical analysis of the options, eliminating those that are technically unfeasible. When more than one option is technically feasible, economics are used to select the preferred option. Economic analysis is best done using NPV or AC. The company's hurdle rate or ROI criterion should be used as the discount rate. ■

Edited by Suzanne Shelley

Authors

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Dust Control in the Chemical Processing Industries

The prevention of dust hazards in the CPI is integral to process-safety management — wide-reaching mitigation schemes must be implemented

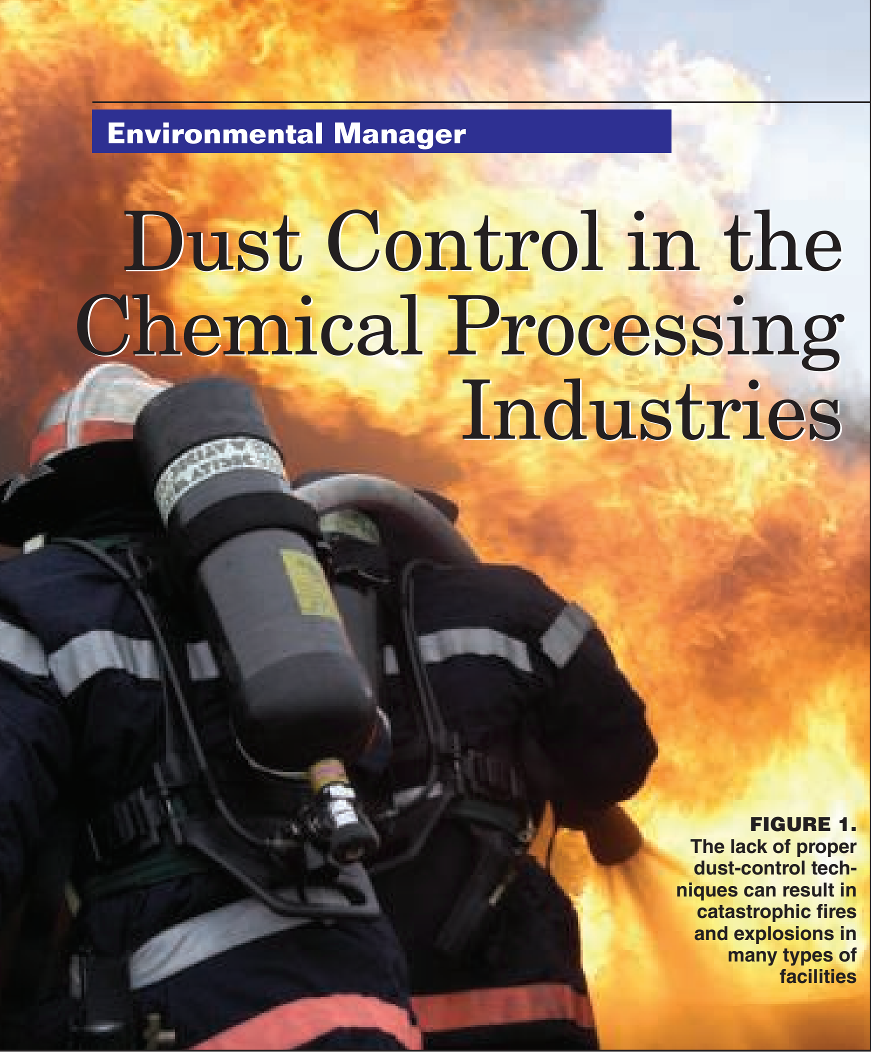

FIGURE 1. The lack of proper dust-control techniques can result in catastrophic fires and explosions in many types of facilities

Walter S. Kessler
Chilworth Technology, Inc.

Dust in the chemical processing industries (CPI) is present in numerous operations, including powder processing; the transport of materials on belt or rotary-screw conveyors; grinding materials in giant shredders and pulverizers; machining, sawing, grinding or sanding operations; dumping bags of materials into reactors; handling coating materials; as well as the processing of pharmaceuticals and foods. An integral industry-safety issue arises when we consider the handling and suppression of the dust and particulate matter associated with these processes, namely preventing the formation of combustible clouds that can create a fire hazard or even trigger an explosion. Such a catastrophic dust explosion in a manufacturing facility is depicted in Figure 1. Additionally, protecting workers from the dangers of potentially dusty environments, including contact irritations and inhalation exposure, is an important factor in determining the methods and extent to which the particulate matter or dust needs to be suppressed or eliminated.

Regulations

Dust hazards are so problematic to employees that the U.S. Occupational Safety and Health Administration (OSHA; Washington D.C.; www.osha.gov) has implemented rules for personal protective equipment (PPE) — specifically dust masks and respirators, under standard 29CFR 1910.134 — to protect workers [*1*]. This standard states: "In the control of those occupational diseases caused by breathing air contaminated with harmful dusts, fogs, fumes, mists, gases, smokes, sprays or vapors, the primary objective shall be to prevent atmospheric contamination. This shall be accomplished as far as feasible by accepted engineering control measures (for example, enclosure or confinement of the operation, general and local ventilation, and substitution of less toxic materials). When effective engineering controls are not feasible, or while they are being instituted, appropriate respirators shall be used pursuant to this section." It goes on to state: "A respirator shall be provided to each employee when such equipment is necessary to protect the health of such employee. The employer shall provide the respirators, which are applicable and suitable for the purpose intended. The employer shall be responsible for the establishment and maintenance of a respiratory protection program. The program shall cover each employee required by this section to use a respirator."

Additionally, the National Fire Protection Association (NFPA; Quincy, Mass.; www.nfpa.org) has stepped in and set consensus standards, based upon good engineering practices, to control and prevent combustible-dust related hazards. NFPA 654 (Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing and Handling of Combustible Particulate Solids) applies to all phases of the manufacture, processing, blending, pneumatic conveying, repackaging and handling of combustible particulate solids or hybrid mixtures, regardless of concentration or particle size, where the materials present a fire or explosion hazard [*2*]. In addition to this standard, the NFPA has also set standards for specific industries and processes, such as: NFPA 61 (Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Products Facilities), NFPA 484 (Standard for Combustible Metals) and NFPA 664 (Standard for the Prevention of Fires and Explosions in Wood Processing and Working Facilities). These standards hold, as a top priority, the action of minimizing and controlling dust and particulate matter in processing industries from both a fire- and explosion-hazard safety standpoint.

In addition to the human-health impact, combustible airborne dust and particulates in the right environment — where confinement, dispersion, concentration, oxidants and ignition are present or potentially present — can create explosions. Combustible dust, according to both OSHA (CPL 03-00-008) and NFPA 654, is defined as a particulate solid that presents a fire or deflagration hazard when suspended in air or some other oxidizing medium over a range of concentrations, regardless of particle size or shape. The most common industrial sources of combustible dust include: food (such as candy, sugar, spice, starch, flour and feed), grain, tobacco, plastics, wood, paper, pulp, rubber, textiles, pesticides, pharmaceuticals, dyes, coal, metals (such as aluminum, chromium, iron, magnesium and zinc), and fossil-fuel power generation [*3*]. When these dusts are ignited, they can produce a fireball 8–10 times larger than the original volume of the cloud in the absence of confinement. Conversely, in a confined environment, explosive pressures can increase to as high as 8–10 times the original pressure.

Control measures

Every dust has unique physical and chemical characteristics that impact its level of hazard. Physical characteristics include size, shape and moisture content, among others. Chemical characteristics include flammability or combustibility, explosibility, susceptibility to thermal degradation and instability, susceptibility to ignition, and chemical reactivity. It should be noted that the physical characteristics of the dust also effect the chemical characteristics. For example, as particle size and moisture content decrease, the maximum explosion potential and maximum rate of pressure rise per unit time increases and the minimum ignition energy (MIE) generally decreases [*4*]. The dust-explosion hazardous classes (ST) range from 0 (no explosion potential) to 3 (very strong explosion potential). Testing of representative dust samples is the best method to classify dust materials. Typically, the cost of testing is recovered in reduced engineering-control costs.

FIGURE 2. Even dust-mitigating equipment can be the source of explosion hazards if not correctly installed and maintained

FIGURE 3. Extra care must be taken any time personnel have direct contact with potentially combustible dusts or solids, for example, when pouring a bag of reactant into a vessel

To control dust and particulate matter, vacuum systems with various forms of filtrations and particle-removal devices have been designed and installed in industry. The engineering and design behind some of these systems can be very detailed and intricate. The key to their design is to move the dust and air at a velocity fast enough to keep the dust or particulate matter suspended and moving inside of transport ductwork until they reach the filter mechanism or cyclone separator. At this point, they are removed from the air to an acceptable level before the air is released back into the facility or outside environment.

These mechanical air-purifying systems are intended for removing dust and particulate matter. An important aspect to their function, besides proper design, is proper maintenance — specifically changing filters and keeping the system clean. This ensures that dust and particulate matter do not build up in the equipment and cause a hazardous fire and explosion scenario; this is the reason they were installed in the first place. In addition to proper design, the installation of explosion-protection (such as venting or suppression systems), explosion-isolation, and spark-detection systems may be required, depending upon the properties of the dust being collected. One might think this is obvious; however, systems installed to mitigate dust and particulate matter have historically been involved in fire and explosion incidents, as seen in the dust-collector explosion in Figure 2.

In some cases, dust is removed through a wet-scrubbing arrangement where the dust or air stream comes into intimate contact with water, and the dust is removed from the air stream. The dust may be dissolved in the water or may create a slurry. In either case, this type of collection requires further treatment of the water solution or sludge for environmental purposes.

In addition to vacuum-bag or filter systems, water and various polymer-additive systems have also been used to control dust, mainly in coal, mining and dirt-road applications. These systems typically consist of a water-only, water-polymer solution or oil-based liquid that is laid down or sprayed onto a surface by a nozzle-manifold or firehose-like system.

Avoiding incidents

Due to the number of incidents related to combustible dust — there have been 281 major events reported from 1980–2005, which have killed 119 workers, injured another 718 workers, and destroyed many industrial facilities [*3,5*] — OSHA reissued its CPL 03-00-008 Combustible Dust National Emphasis Program (NEP) on March 11, 2008. Although OSHA does not yet have its own standard pertaining to combustible dust, the agency cites combustible-dust hazards, including fire deflagration, explosion and related hazards under the General Duty Act of 1970. This act states that an employer shall furnish to each of his employees employment and a place of employment which are free from recognized hazards that are causing or are likely to cause death or serious physical harm to his or her employees [*6*], and relies on NFPA standards for the recognition of such hazards. This includes the statement that employers must furnish each employee with a place of employment that is free from recognized hazards that are causing, or are likely to cause, death or serious physical harm. In 2007–2009, OSHA conducted approximately 1,100 combustible-dust inspections and issued over 4,900 citations for both combustible-dust hazards and other safety violations. From these violations, the following list summarizes some of the General Duty Violations issued by the OSHA inspectors [*7*]:

- Dust collectors were located inside buildings that lacked proper explosion-protection systems, including for venting and suppression purposes
- The rooms with excessive dust accumulations were not equipped with explosion-relief venting distributed over the exterior walls and roofs of the buildings
- The horizontal surfaces, including those on beams, ledges and screw conveyors at elevated surfaces, were not minimized to prevent accumulation of dust
- Equipment, such as grinders, shakers, mixers and ductwork, were not maintained to minimize escape of dust into the surrounding work area. This becomes especially problematic when employees may have direct contact with powder or dusty materials, such as when pouring bags into reactors or vessels (Figure 3). Also, the employer did not prevent the escape of dust from the packaging equipment, creating a dust cloud in the work area
- Interior surfaces where dust accumulations could occur were not designed or constructed to facilitate cleaning or to minimize combustible-dust accumulations. Regular cleaning frequencies were not established for walls, floors and horizontal surfaces, such as ducts, pipes, hoods, ledges and beams
- Compressed air was periodically used to clean up the combustible-dust accumulation in the presence of ignition sources
- Explosion vents on dust collectors and bucket elevators were directed into work areas and not vented to a safe, outside location away from platforms, means of egress or other potentially occupied areas
- Process hazard analysis (PHA) was not conducted to determine whether the process hazards necessitated the installation of approved devices, such as explosion-protection systems, interlocked rotary valves, deflagration vents and flame-front diverters
- The employer did not provide adequate maintenance and design of dust-collector systems, which created insufficient air aspirations, low duct velocities and blocked ducts

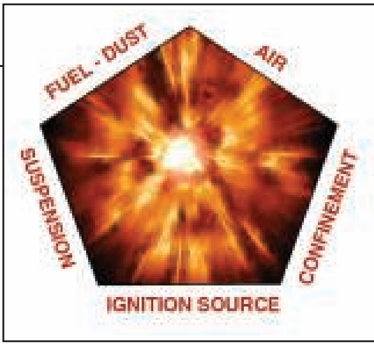

FIGURE 4. The dust explosion pentagon represents the conditions that can lead to a catastrophic event

Even with OSHA implementing the NEP program, combustible-dust related incidents continue to be a major industrial problem in the U.S. and globally. There were over 500 combustible-dust related incidents reported in 2011 in the U.S. alone [*8*]. That number does not include the events associated with grain elevators or coal-fired power plants, or smaller flash fires that were quickly extinguished, as well as other near-misses that failed to be reported.

From the above list, some good rules of thumb and generally accepted good engineering practices for facilities that contain dust and particulate matter from production are [*9*]:

- Implement appropriate engineering designs and controls to minimize the presence of dust and to prevent the dust explosion pentagon (Figure 4) from occurring
- Perform manufacturer-recommended maintenance on all equipment to ensure that it is functioning as designed
- Implement good housekeeping practices, including using surfaces that minimize dust accumulation, periodic inspections for hidden areas of dust accumulation and controlling sources that could cause dust to become airborne to maintain a clean, dust-free working environment
- Follow other measures, including: bonding of equipment to ground to control static electricity; controlling smoking and sources of open flames and sparks; managing friction and other sources for mechanical sparks
- Provide hazard recognition training for employees per OSHA 3371-08 2009
- Establish overall safe work practices, such as proper electrical-area classifications, physical barriers for the hazard, cleaning that does not generate dust clouds and locating relief valves away from dust
- Report and record any and all incidents or near-misses, as they are a valuable tool and resource for preventing larger, more serious incidents

With all these recommendations, regulations, reported incidents and near-misses, facilities should strongly consider use of competent personnel and knowledge-

able individuals to provide testing, hazard assessments, risk analysis studies and engineered solutions to minimize or control dangerous dusts and particulate matter in manufacturing.

To achieve process-safety excellence, employees must be genuinely proficient and competent in their requisite technical disciplines, and appropriate levels of knowledge must be embedded in key positions throughout an organization with a mechanism for longevity. Or, put more simply, organizations must have "the right people, with the right skills, implementing appropriately designed process-safety programs, motivated by the right organizational culture, in the right way." Results are far-reaching and broad, affecting finances, the environment and most of all, workforce safety. Properly managing dust protects the workforce, facility and the environment, while maintaining stakeholder confidence and encouraging compliance with all legislation and avoiding regulatory intervention. Eliminating or minimizing dust is a small investment compared to the costs of the harm that can occur if not appropriately addressed. ■

Edited by Mary Page Bailey

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Fractionation Column

Reflecting on a milestone

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

This is my fiftieth editorial in *Chemical Engineering*. There have been several surprises, going all the way back to the beginning in 2010, when I was first asked if I would like to author a monthly editorial. I said that I would, but only if I could inject some "personality" and "funny stuff" into the editorials. My first editorial debuted in the March 2010 issue of *CE*.

Since then, I've covered many topics in this column including some that are very technical, as well as management and personnel subjects, and other less technical topics.

The topic that I have addressed most often is safety. I described some of my "near misses" going back to the 1970s, when too many safety programs focused solely on personal protective equipment. Back then, there were too many near misses and also too many "non misses." Hopefully, some of these editorials encouraged readers to expect the unexpected. My most popular editorial was clearly Crow's Nest (*Chem. Eng.*, February 2011, p. 25) where I described falling off of a column ladder and where many friends and readers seemed to enjoy reading about the resultant extreme physical discomfort.

Along the way, I have received some email comments regarding the "funny stuff." Some readers objected and stated that they read "the magazine for the technical content, not the jokes." Two unfunny editorials also garnered negative responses. When I complained about the plastic refuse of bottled water and contended that some of that water originates from municipal supplies, some vendors objected. When I compared and contrasted pilot plant researchers and computer-simulation researchers, some of the latter felt slighted.

The email comment that I have received most often about this column, however, is a very positive one — "it's the first thing that I read." This could be indicative that some readers might indeed be looking for the "funny stuff." These editorials are "easy reads" compared to many of the things that we have on our desks.

People who know me well, know that I do not mind embarrassing myself, occasionally. Regarding the personal stories that I tell, I assure you that all are totally true. Yes, Robert Kohler and I were on the verge of being shot by young Hungarian soldiers after our taxi driver purposely chose not to stop at an inspection booth at the Austria-Hungary border (Who says ChE careers aren't adventurous?, *Chem. Eng.*, October 2012, p. 55).

After my own personal experiences, my next source of editorial ideas has been AIChE meetings. I must say that I am surprised that I am not ever recognized in hallways at those meetings. Maybe I should wear my hard hat more often.

When I look back, the opportunity to write these editorials has been my number two career highlight. The fact that so many of you are reading them is number one, truly. I would be remiss if I did not mention that Joella Redden, FRI's technical associate, has performed research work for many of them. Dorothy Lozowski edits my drafts with extreme patience. I thank them — and you! ■

Mike Resetarits

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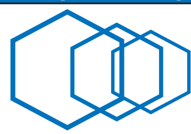

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15	30	45	60	75	90	105	120	135	150	165	180	195	210	225	240	255	270	285	300	315	330	345	360	375	390	405	420	435	450	465	480	495	510	525	540	555	570	585	600

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Classified Index July 2014

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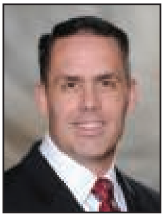
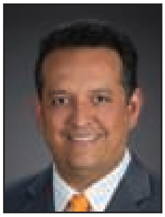
JULY WHO'S WHO


Stubblefield


Howell


Weston


Rodriguez


Evertz

Ted Nelson joins **Akron Rubber Development Laboratory** (Akron, Ohio) as technical advisor.

Michael Stubblefield becomes CEO of **Avantor Performance Materials** (Center Valley, Pa.), a developer of high-performance chemistries.

Ronen Tchelet joins biotechnology company **Dyadic International** (Jupiter, Fla.), as vice president of business development. *Andre Klaassen* joins the company as director of sales for Europe.

Jeff Reilly becomes president of strategy and business development for engineering and project-management firm **AMEC** (London, U.K.).

SSOE Group (Toledo, Ohio), a global engineering, procurement and construction management firm, names *Bob Howell* president and CEO, replacing *Tony Damon*, who is retiring.

Aggreko plc (Houston, Tex.), a provider of temporary power- and temperature-control, services appoints *Chris Weston* as CEO. The company also names *Carole Cran* CFO and executive director.

Mario Rodriguez becomes general director of Mexican operations for **Intelligrated** (Cincinnati, Ohio), a provider of automated material-handling solutions.

Andreas Evertz becomes CEO of **Schenck Process Holding GmbH** (Darmstadt, Germany), a manufacturer of industrial measuring technologies. ■

Suzanne Shelley

BUSINESS NEWS

PLANT WATCH

Ineos licenses HDPE process technology in Turkmenistan

June 10, 2014 — Ineos Technologies (Rolle, Switzerland; www.ineos.com) has licensed its Innovene S process technology for the Turkmengas petrochemical complex in the Balkan Region of Turkmenistan. The new complex will produce 386,000 metric tons per year (m.t./yr) of high-density polyethylene (HDPE) alongside a 50,000-m.t./yr Ineos carbon-black compounding line.

Umicore to construct catalyst manufacturing plant in Poland

June 10, 2014 — Umicore N.V. (Brussels, Belgium; www.umicore.com) has announced the construction of a production facility in Nowa Ruda, Poland, for emission-control catalysts used in cars and trucks. With an investment of around €40 million, completion of the plant is planned for early 2016.

Altana doubles U.S. production capacity for additives

June 6, 2014 — Altana AG (Wesel, Germany; www.altana.com) has opened a new additives manufacturing plant, expanding production capacity at a facility located in Wallingford, Conn. for its additives subsidiary BYK USA Inc. This expansion more than doubles BYK's U.S. additives production capacity and represents a $50 million investment from Altana.

Wacker plans capacity expansion for dispersible polymer powders

June 2, 2014 — Wacker Chemie AG (Munich, Germany; www.wacker.com) is investing around €20 million to expand its production capacity for dispersible polymer powders by building a new 50,000-m.t./yr spray dryer at its Burghausen, Germany site. The facility is scheduled for completion in early 2015.

Topsøe lays foundation for integrated methanol and ammonia plant in Russia

June 2, 2014 — A foundation-laying ceremony was held in Russia for petrochemical company Shchekinoazot's new methanol and ammonia co-production plant. The new plant will be the first ever in the world using Haldor Topsøe A/S's (Lyngby, Denmark; www.topsoe.com) IMAP (Integrated Methanol and Ammonia Production) technology. The plant's capacity will be 1,350 m.t./day of methanol and 415 m.t./d of ammonia. Startup is planned for 2017.

Dow awards Fluor EPC contract for Saudi RO-membrane manufacturing facility

May 28, 2014 — The Dow Chemical Company (Midland, Mich.; www.dow.com) has awarded Fluor Corp. (Irving, Tex.; www.fluor.com) the engineering, procurement and construction contract for its reverse osmosis (RO) manufacturing facility in Saudi Arabia. The facility will manufacture RO elements for water purification. This is Dow's first facility of its kind built outside the U.S., and completion is expected by the end of 2015.

BASF to build new PAG lubricants plant in Ludwigshafen

May 26, 2014 — BASF SE (Ludwigshafen, Germany; www.basf.com) has announced the construction of a new plant for polyalkylene glycol (PAG)-based lubricants at its Ludwigshafen site. The facility will begin operations by early 2016 and produce both PAG lubricant base stocks and formulated blends.

Jacobs awarded contract for chlorine dioxide plant in Indonesia

May 23, 2014 — Jacobs Engineering Group Inc. (Pasadena, Calif.; www.jacobs.com) was awarded a contract by P.T. OKI Pulp and Paper Mills (Jakarta, Indonesia) for the design and supply of an integrated chlorine dioxide plant for its pulp mill project in South Sumatra, Indonesia. With commissioning scheduled in 2016, the plant is anticipated to produce 172 m.t./d of chlorine dioxide.

Evonik begins production at isophorone facilities in China

May 19, 2014 — Evonik Industries AG (Essen, Germany; www.evonik.com) has commenced production at an integrated complex for isophorone and isophorone diamine in Shanghai, China. The company has invested over €100 million in the facilities, which will have a total production capacity of 50,000 m.t./yr, serving customers in the coatings and paint, construction, adhesives, and composite industries in Asia.

MERGERS AND ACQUISITIONS

A. Schulman acquires Specialty Plastics business from Ferro

June 4, 2014 — A. Schulman, Inc. (Akron, Ohio; www.aschulman.com) agreed to purchase a selected majority of the assets of the Specialty Plastics business segment from Ferro Corp. (Mayfield Heights, Ohio; www.ferro.com), which develops specialty compounds, colors and coatings.

Westlake acquires German PVC producer Vinnolit

May 28, 2014 — Westlake Chemical Corp. (Houston; www.westlake.com) has agreed to acquire polyvinyl chloride (PVC) manufacturer Vinnolit Holdings GmbH for €490 million. The acquisition includes Vinnolit's operations in Germany and the U.K., comprising a combined production capacity of 780,000 m.t./yr of PVC, 665,000 m.t./yr of vinyl chloride monomer and 475,000 m.t./yr of membrane-grade caustic soda.

Sabic and SK Global form polyethylene joint venture

May 27, 2014 — Saudi Basic Industries Corp. (SABIC; Riyadh, Saudi Arabia; www.sabic.com) and SK Global Chemical (Seoul, South Korea; www.skglobalchemical.com), have signed a 50-50 joint venture (JV) agreement for a total investment of $595 million to manufacture a range of polyethylene (PE) products. The Singapore-based JV is expected to operate a series of manufacturing plants, the first of which is in Ulsan, South Korea, with a PE production capacity of 230,000 m.t./yr.

Sika to acquire Swiss adhesives manufacturer Klebag

May 23, 2014 — Sika AG (Baar, Switzerland; www.sika.com) is acquiring the business of Klebag Chemie AG, a manufacturer of adhesives for the sealing, bonding and flooring markets. Last year, Klebag generated net sales of CHF 12 million (around $13.4 million).

Ineos and Doeflex plan merger for S-PVC businesses

May 23, 2014 — The Compounding division of Ineos Technologies and Doeflex Compounding (Wiltshite, U.K.; www.doeflex.co.uk) have announced the intention to merge their S-PVC (suspension polyvinyl chloride) compounding businesses. The combined business would be managed by an integrated team from both entities.

Mitsui Chemicals to sell organic acids business to Fuso

May 16, 2014 — Mitsui Chemicals Inc. (MCI; Tokyo; www.mitsuichem.com) has announced that it will transfer its organic acids business to Fuso Chemical Co. (Osaka, Japan; www.fusokk.co.jp). The sale includes production capacity at the Kashima Works facility in Kamisu City, Japan, consisting of 32,000 m.t./yr maleic anhydride and 15,000 m.t./yr fumaric acid. ■

Mary Page Bailey

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

July 2014; VOL. 121; NO. 7

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Economic Indicators

2012 2013 2014

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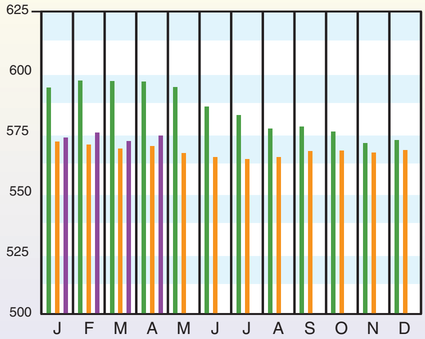
CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957–59 = 100)	Apr.'14 Prelim.	Mar.'14 Final	Apr.'13 Final
***CE* Index**	573.6	571.5	569.4
Equipment	695.9	692.9	689.5
Heat exchangers & tanks	633.9	627.9	626.2
Process machinery	664.7	662.9	656.5
Pipes, valves & fittings	874.5	876.1	875.6
Process instruments	408.9	410.4	413.2
Pumps & compressors	937.3	932.9	924.5
Electrical equipment	514.4	514.6	512.6
Structural supports & misc	767.3	760.5	746.8
Construction labor	320.3	319.6	319.8
Buildings	542.3	542.3	536.5
Engineering & supervision	322.9	322.5	327.6

Annual Index:

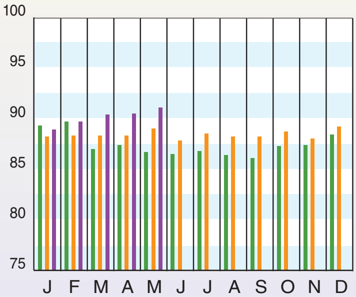
2006 = 499.6
2007 = 525.4
2008 = 575.4
2009 = 521.9
2010 = 550.8
2011 = 585.7
2012 = 584.6
2013 = 567.3



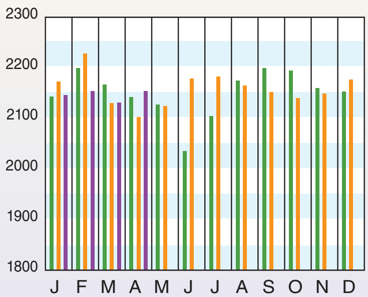
CURRENT BUSINESS INDICATORS*

	LATEST			PREVIOUS						YEAR AGO		
CPI output index (2007 = 100)	May '14	=	91.1	Apr. '14	=	90.5	Mar. '14	=	90.4	May '13	=	89.0
CPI value of output, $ billions	Apr. '14	=	2,154.4	Mar. '14	=	2,131.9	Feb. '14	=	2,154.1	Apr. '13	=	2,103.2
CPI operating rate, %	May '14	=	76.7	Apr. '14	=	76.3	Mar. '14	=	76.3	May '13	=	75.8
Producer prices, industrial chemicals (1982 = 100)	May '14	=	288.4	Apr. '14	=	295.7	Mar. '14	=	293.7	May '13	=	303.0
Industrial Production in Manufacturing (2007 = 100)	May '14	=	99.5	Apr. '14	=	98.9	Mar. '14	=	99.0	May '13	=	96.1
Hourly earnings index, chemical & allied products (1992 = 100)	May '14	=	154.9	Apr. '14	=	156.6	Mar. '14	=	156.7	May '13	=	156.7
Productivity index, chemicals & allied products (1992 = 100)	May '14	=	108.7	Apr. '14	=	109.0	Mar. '14	=	107.4	May '13	=	105.8

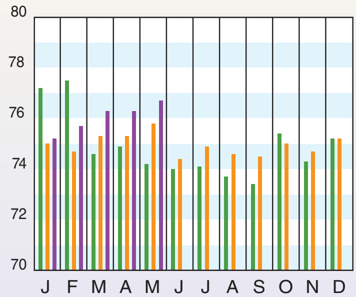
CPI OUTPUT INDEX (2007 = 100)



CPI OUTPUT VALUE ($ BILLIONS)



CPI OPERATING RATE (%)



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

HIGHLIGHTS FROM RECENT ACC ECONOMIC DATA

The Chemical Activity Barometer (CAB) for May reached its highest peak since February 2008, while also posting its highest year-over-year gain since September 2010. The CAB is a leading economic indicator created by the American Chemistry Council (ACC; Washington, D.C.; www.americanchemistry.com). Measured on a three-month moving average (3MMA) basis, the CAB realized a healthy 0.8% gain over April, and is up a solid 4.1% over this time last year. The data reflect upward revisions for the previous five months, suggesting more than just a rebound from the adverse winter months. "The index reveals that the underlying fundamentals are good," said Kevin Swift, chief economist at ACC.

In other economic data from a recent ACC Weekly Chemical and Economic Report, market volumes for U.S. specialty chemicals were flat in April, following a 1.3% gain in March and 0.3% gain in February. Also in April, 10 of the 28 specialty chemical market segments monitored by the ACC saw expansion, while 17 segments declined, and one was flat. In contrast, 23 segments expanded in March. Compared to a year ago at this time, all market segments except four (plastic additives, plasticizers, paper additives and dyes) show higher volumes, according to the recent ACC report.

In chemical equity performance, the S&P index for chemical companies was up 8.5% from the beginning of 2014, while the wider S&P 500 index was up 4.1%, ACC said in another recent ACC Weekly Chemical and Economic report. "Thus far this year, chemical equities have far outstripped the overall market on a year-over-year comparison basis," the report said.

Overall employment in the U.S. chemical industry rose by 2,200 jobs in May to reach a total of 800,100. The ACC report said the gain was centered in production workers. ❑

CURRENT TRENDS

The preliminary value for the April *CE* Plant Cost Index (CEPCI; top; the most recent available) rose 0.4% from the final March value, after dropping the previous month. The gain was mostly due to a rise in the Equipment subindex. The Engineering Supervision and Construction Labor subindices rose slightly, while the Buildings subindex was unchanged. The overall PCI value for April 2014 stands at 0.75% higher than the value from April of last year. Meanwhile, updated values for the Current Business Indicators (CBI) from IHS Global Insight (middle) saw both the CPI Output Index and the CPI Value of Output rise from the previous month's values, while the Productivity Index for chemicals dipped slightly. ❑