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August 2014

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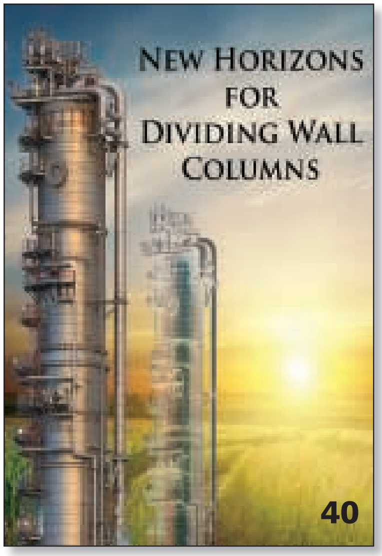

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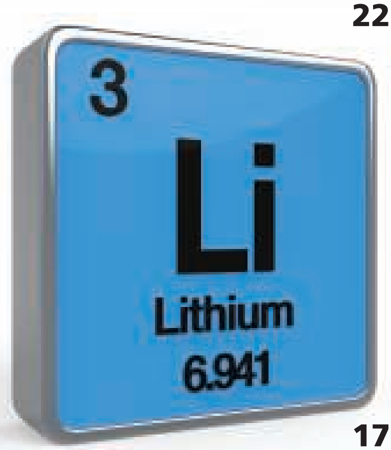

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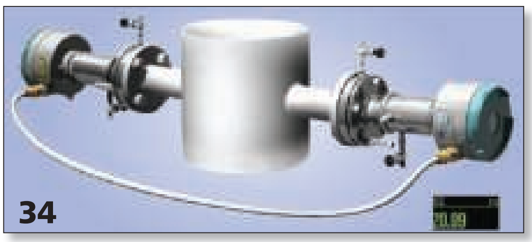

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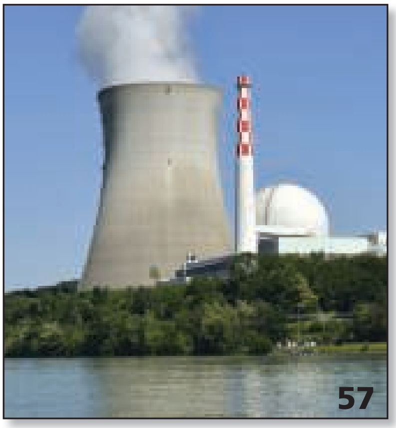

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BPA

Editor's Page

Heading off the 'carbon bubble'

The newest voices calling for action by industry on climate change issues are not the regulators, politicians, industry spokespeople, engineers or scientists. They come from a potentially far more influential group: the financial analysts and economists of an organization called the Carbon Tracker Initiative (London, U.K., www.carbontracker.org). Carbon Tracker approaches the issue of climate change as an exercise in understanding and managing risk. The chemical process industries (CPI) need to take notice of Carbon Tracker's findings, because they could have far-ranging implications for the future of our companies.

The findings of Carbon Tracker's report, which was released about two years ago and has received great acclaim in sustainability circles, are slowly beginning to sink in with industry, and are as follows:

- To avoid the risk of irreversible climate change, the world effectively has a budget for the carbon dioxide that can be released into the environment by using fossil fuels. That budget has been calculated at 886 billion metric tons (Gtons) of CO_2 over the first 50 years of this century. But just 11 years into the 50-yr period, Carbon Tracker found that one third of the 886 Gtons had already been emitted
- If you take all of the fossil reserves owned by governments, public and private companies, they are the equivalent of 2,795 Gtons of CO_2. That means that only about 20% of fossil fuel reserves can be burned without taking steps to mitigate the corresponding emissions
- It also implies that the publicly traded companies that own the reserves are over-valued on their respective stock markets, since a lot of what they own is simply unburnable. In effect, they own "stranded assets" that cannot be exploited

Major players in fossil fuels have already been active in refuting Carbon Tracker's findings. Their view is that the rapidly escalating world population will need cost-effective energy and that their reserves cannot therefore be "stranded."

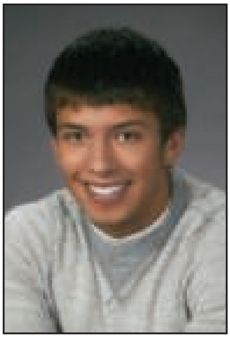
Imagine for a moment that there is sufficient pressure that fossil fuel reserves truly become stranded. Where would that leave the CPI? Here are some ideas for research and development that the industry should be undertaking — maybe with some urgency: 1) Using CO and CO_2 as feedstocks for fuels and plastics. Several companies are already investigating this way forward; 2) Improving biotechnology routes to common chemicals and plastics, minimizing water and energy use, and ensuring that they are thermodynamically realistic; 3) Aiming for a "circular chemical economy." This is a concept in which the CPI have two streams — bio-components, which return to the environment after use, and technical components, which are almost endlessly recyclable into new products. Whether a true circular economy is possible or not, there is a need for the CPI to get closer to the brand owner and consumer, and design materials for their recyclability.

With all of the hoopla surrounding shale gas, it may seem that the path for expansion in the CPI still depends on cheap feedstocks and ever-growing production of commodity products. But whether you believe or disbelieve climate science, a time is coming when more inputs and outputs into CPI processes will be priced or taxed. Now is the time to realize the risks and opportunities associated with climate change, and get ahead of them. ■

John Pearson,
CEO, Chemical Industry Roundtables

Letters

Chopey scholarship awarded



The 2014 Nicholas P. Chopey Scholarship for Chemical Engineering Excellence has been awarded to Stephen Vitello, who is studying chemical engineering at The State University of New York College at Buffalo (www.buffalo.edu). Vitello is a member of Tau Beta Pi (National Engineering Honor Society), is a National Society of Collegiate Scholar and is on the Dean's List. Vitello graduated from Grand Island High School (Grand Island, N.Y.). He expects to graduate with his degree in chemical engineering in 2015.

About the scholarship

Bringing recognition to the chemical engineering profession and striving to continually advance that profession have been goals of *Chemical Engineering* magazine since its founding in 1902. To help advance those goals, *CE* established the annual Chopey Scholarship for Chemical Engineering Excellence in late 2007. The award is named after Nicholas P. Chopey, the magazine's former Editor-in-Chief, who made many valuable and long-lasting contributions to *CE* over the 47 years that he devoted to it. To honor his contributions to the chemical engineering profession, *CE* established the scholarship in his name.

Applicant qualifications. The scholarship is awarded to current third-year students who are enrolled in a fulltime undergraduate course of study in chemical engineering at one of the following four-year colleges or universities, which include Mr. Chopey's alma mater and those of our editorial staff:

- SUNY Buffalo
- Columbia University
- Rutgers University
- University of Kansas
- University of Virginia
- University of Oklahoma

The scholarship is a one-time award. The program utilizes standard Scholarship America recipient-selection procedures, including the consideration of past academic performance and future potential, leadership and participation in school and community activities, work experience, and statement of career and educational goals.

Postscripts, corrections

June 2014, "Capital Cost Indices", p.28. In the "Facts at your Fingertips" column, a weighting scheme for the four main components of the *Chemical Engineering* Plant Cost Index (CEPCI) was reported incorrectly. The numbers used are out-of-date. The current weighting for the four sub-indices of the CEPCI is as follows: Equipment (50.7%); Construction labor (29.0%); Engineering and supervision (15.8%); and Buildings (4.6%). The corrected version of the full article can be found at www.che.com.

Circle 11 on p. 68 or go to adlinks.che.com/50979-11

Calendar

NORTH AMERICA

5th Biobased Chemicals Conference: Commercialization & Partnering. Global Tech Community (Monrovia, Calif.). Phone: 626-256-6405; Web: gtcbio.com
San Francisco, Calif. **Sept. 18–19**

43rd Turbomachinery and 30th Pump Users' Symposia. Texas A&M University (College Station, Tex.). Phone: 979-845-7417; Web: pumpturbo.tamu.edu
Houston **Sept. 22–25**

WEFTEC. Water Environment Federation (Alexandria, Va.). Phone: 571-830-1545; Web: weftec.org
New Orleans, La. **Sept. 30–Oct. 1**

AFPM Q&A and Technology Forum. American Fuel & Petrochemical Manufacturers (AFPM; Houston). Phone: 202-457-0480; Web: afpm.org
Denver, Colo. **Oct. 6–8**

WJTA-IMCA Expo. Water Jet Technology Assn. and Industrial & Municipal Cleaning Assn. (St. Louis, Mo.). Phone: 314-241-1445; Web: wjta.org
New Orleans, La. **Oct. 13–15**

Next-Generation Filter-Media Conference. American Filtration and Separations Soc. (Nashville, Tenn.). Phone: 615-250-7792; Web: afssociety.org
Chicago, Ill. **Oct. 14–15**

AFPM Environmental Conference. AFPM (Houston). Phone: 202-457-0480; Web: afpm.org
San Antonio, Tex. **Oct. 19–21**

Gasification Technologies Conference 2014. Gasification Technologies Council (Arlington, Va.). Phone: 703-276-0110; Web: gasification.org
Washington, D.C. **Oct. 26–29**

International Lubricants & Waxes Conference. AFPM (Washington, D.C.). Phone: 202-457-0480; Web: afpm.org
Houston **Nov. 13–14**

EUROPE

Chemical Plant Commissioning. IChemE (Rugby, U.K.) and the Univ. of Leeds (Leeds, U.K.). Phone: +44-113-343-2494/8104; Web: engineering.leeds.ac.uk/cpd
Hamburg, Germany **July 9–11**

Biocat2014 — 7th International Congress on Biocatalysis. Hamburg University of Technology (Hamburg, Germany). Phone: +49-40-76629-6551; Web: biocat2014.de
Hamburg, Germany **Aug. 31–Sept. 4**

10th European Soc. of Biochemical Engineering Sciences and 6th International Forum on Industrial Bioprocesses. University of Lille (Lille, France),

in collaboration with the American Chemical Soc. (Washington, D.C.). Fax: +33-3-28-76-73-56; Web: esbes-ifibiop-lille2014.com
Lille, France **Sept. 7–10**

Practical Distillation Technology. IChemE (Rugby, U.K.), Phone: +44-1788-534431; Web: icheme.org/pdt
London, U.K. **Sept. 8 –10**

Advances in Process Control and Automation. IChemE (Rugby, U.K.), Phone: +44-20-7927-8200; Web: icheme.org
York, U.K. **Sept. 15–17**

IWA World Water Congress & Exhibition 2014. Match+ and IWA Exhibition Management (The Hague, the Netherlands). Phone: +31-70-382-0028; Web: iwa2014lisbon.org
Lisbon, Portugal **Sept. 21–26**

6th Symposium on Continuous Flow Reactor Technology for Industrial Applications. TeknoScienze Srl. (Milan, Italy). Phone: +39-2-36799603; Web: flowchemistrytks.com
Budapest, Hungary **Sept. 24–26**

ICBR 2014 — 19th International Congress for Battery Recycling. ICM AG (Birrwil, Switzerland). Phone: +41-62-785-1000; Web: icm.ch
Hamburg, Germany **Sept. 24–26**

Powtech 2014. Nuremberg Messe GmbH (Nuremberg, Germany). Phone: +49-911-8606-8355; Web: powtech.de
Nuremberg, Germany **Sept. 30–Oct. 2**

7th Green Solvents Conference 2014. Dechema e.V. (Frankfurt am Main, Germany). Phone: +49-69-7564-333; Web: icm.ch
Dresden, Germany **Oct. 19–22**

ASIA & ELSEWHERE

IndoPlas — 9th Annual International Plastics Exhibition. Messe Düsseldorf Asia Pte. Ltd. (Singapore). Phone: +65-6332-9620-; Web: indoplas.com
Jakarta, Indonesia **Sept. 3–6**

4th International Symposium on Environmental Biotechnology and Engineering. Cinvestav (Mexico City, Mex.). Phone: +5255-5747-3800, Ext. 4324; Web: isebe.cinvestav.mx/
Mexico City, Mexico **Sept. 9–12**

China Petroleum & Chemical International Conference. China Petroleum and Chemical Industry Federation (CPCIF; Beijing, China). Phone: 650-863-2491; Web: http://www.cvent.com/d/d4q171
Tianjin, China **Sept. 10–12** ■

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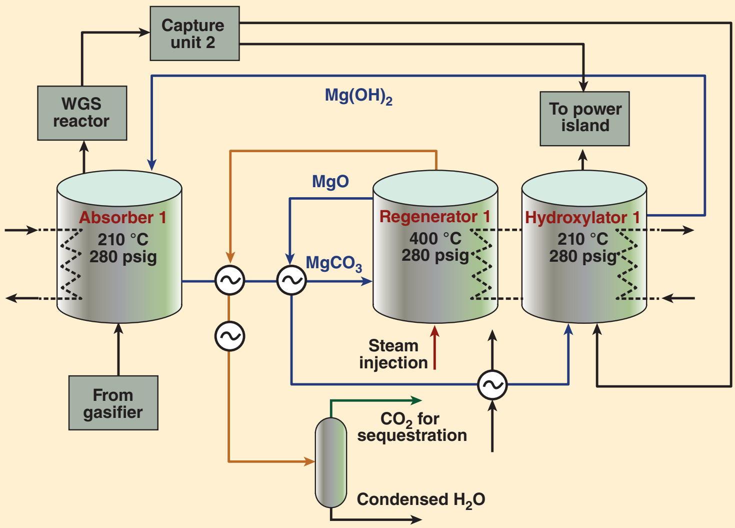
A sorbent that enhances the water-gas shift reaction

Scientists at the National Energy Technology Laboratory (NETL; Morgantown, W. Va.; www.netl.doe.gov) have demonstrated a process for enhancing the efficiency of the water-gas shift (WGS) reaction. The process revolves around a magnesium hydroxide sorbent material that can remove CO_2 from coal gasification products at elevated temperatures. The industrially significant WGS reaction, often used to increase H_2 gas concentration following gasification, is equilibrium-limited, and the carbon dioxide removal helps drive the reaction in the forward direction.

In a conventional WGS process using pressure-swing absorption technology, CO_2 removal occurs at below 50°C, which necessitates cooling and reheating steps that reduce the overall efficiency of the process. The NETL process (see flowsheet) uses a patented $Mg(OH)_2$ sorbent material to remove CO_2 at a temperature between 200 and 300°C, which is ideal for gas entering a WGS reactor. The ability to remove CO_2 at higher temperatures retains most of the thermal energy of the steam and improves overall efficiency. The sorbent material can be regenerated at temperatures of 400°C, significantly lower than other sorbents reported in the scientific literature, says the NETL research team, led by Ranjani Siriwardane.

The $Mg(OH)_2$ sorbent can react with CO_2 to form a carbonate and water, making it a source of steam for the WGS reaction. Its ability to generate water minimizes the steam-injection requirements for the WGS reaction, says Siriwardane. Additional steam is required to maintain the ideal water-to-CO ratio for the WGS. But the additional steam requirement saps the efficiency of the process. The chemistry of the sorption process reduces the amount of steam traditionally required for the WGS reactor by 50%, thus increasing the overall plant efficiency, the NETL research team says.



The patented method was designed for an integrated gasification combined cycle (IGCC) plant, but can be used elsewhere. It has been demonstrated in NETL laboratories for over 100 cycles, and the technology is available for licensing.

A heavy-metal recovery technique that produces no waste streams or sludge

A new remediation approach for industrial heavy-metal waste has been developed by Lewis Environmental Services, Inc. (LES; Pittsburgh, Pa.; www.lesvc.com). The patented Enviro-Clean process adsorbs heavy metals from liquid waste streams onto a bed of specially treated granular activated carbon. Then, when the activated carbon is spent and loaded with heavy metals, the activated carbon is chemically stripped to clean the carbon for reuse and to concentrate the heavy metals in the stripping solution. The solution is then processed in an electrolytic cell where the metals are plated on a cathode. The metals in the stripping solution can be selectively recovered to produce a high-purity metal for sale to third-party refiners.

Capable of treating single- or multicomponent waste streams, this process is applicable to a very broad range of metals, including chromium, lead, zinc, cadmium, copper, nickel, silver, iron, mer-

(Continues on p. 12)

Advance in UF module

The latest offering of ultrafiltration systems from Evoqua Water Technologies (Alpharetta, Ga.; www.evoqua.com) incorporates an advanced polyvinylidene fluoride (PVDF) membrane into a hydraulically balanced, modular filtration system. Known as Memcor CPII, the product employs a PVDF membrane with a uniform, but asymmetric morphology that forms a dense, permeable "skin" layer over an open substructure.

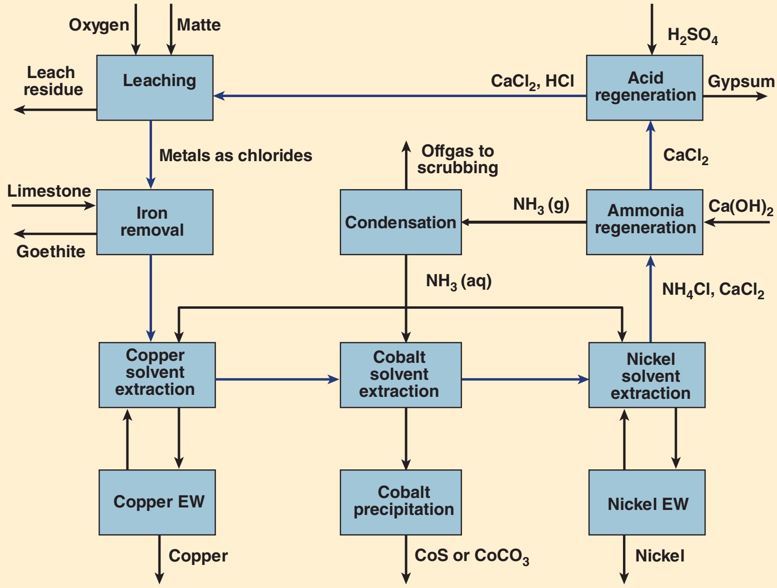
The membrane allows high permeability with good abrasion resistance and can achieve less than 5% flow variance among the filtration units, says Russ Swerdfeger, product manager for Memcor at Evoqua. The membranes are used with optimized modules that are assembled in up to 32-unit racks. The racks are very compact and easily accessible to minimize the footprint, reduce installation costs and simplify system operations. The new CPII system is being deployed as a pretreatment strategy for reverse osmosis units, and boiler feedwater.

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

This chloride leaching process recycles resources

Outotec Oyj (Espoo, Finland; www.outotec.com) has developed a new chloride-based leaching process for recovering nickel from nickel matte — a commercial intermediate product of nickel smelting that contains about 65% of nickel. Developed since the 1980s, originally for Cu recovery and since extended to Ni, Zn and Au, the Outotec Nickel Matte Chloride Leaching process is a more resource-efficient and environmentally sustainable option for Ni refining compared to existing leaching processes, says Kaarlo Haavanlammi, technology manager — Nickel Hydrometallurgy. Besides Ni matte, the process can be modified to treat all sulfidic nickel concentrates, as well as low-grade sulfides (<5% Ni), says Haavanlammi.

The new process (flowsheet) is based on a calcium chloride solution, which enables easy acid (HCl) and base (NH_3) regeneration in the process. Leaching is performed in acidic conditions (pH low enough to prevent Fe precipitation), using HCl solution from acid regeneration, and the addition of O_2 (to prevent H_2 formation). Leaching is performed in multiple steps at near boiling point temperatures and atmospheric pressure for 10–15 h. After leaching, the metals (Fe, Cu, Co and Ni) are recovered from the chloride solution by solvent extractions, and then purified by electrowinning. NH_4Cl produced in the extraction raffinate is regenerated into NH_3, and the $CaCl_2$ solution from



NH_3 regeneration is routed to acid regeneration, where sulfuric acid is added and gypsum is precipitated. HCl generated in this step is reused for leaching.

In laboratory scale piloting, this chloride leaching process has achieved recoveries of 99% (Ni and Co) and 98% (for Cu), says Haavanlammi, and the company has confirmed the materials of construction in the pilot-demonstration plant. The process is ready for a first commercial-scale plant.

HEAVY-METAL RECOVERY

(*Continued from p. 11*)

cury, manganese, molybdenum and more. Unlike other metal-removal methods, the Enviro-Clean process is not based on chemical precipitation or regeneration, both of which generate hazardous waste streams that require further treatment. The Enviro-Clean process produces no hazardous waste or sludge, instead resulting in a recyclable effluent, along with its recovered metallic products. This effluent can meet very low discharge limits for heavy-metal content, achieving less than 10 parts per billion (ppb).

LES stresses that the process is quite versatile, because most commercially available activated-carbon products can be used as feedstock for the modular unit. Additionally, the process can be either retrofitted into an existing layout or installed into new facilities. The closed-loop nature of the process (resulting in recyclable effluent, as opposed to hazardous waste) results in reductions in water usage and sludge-disposal costs. Also, the use of activated carbon rather than other materials allows for non-hazardous specifications to be applicable, providing further cost savings. Currently, LES sees viable applications for the Enviro-Clean treatment in the fields of printed circuit-boards, steel and coil coatings, aluminum windows, high-speed electroplating, chrome plating and acid-mine drainage. Future iterations of this technology are planned that will address the recycling of wastewater from hydraulic fracturing (fracking) operations. Also, a similar catalytic activated-carbon process has been developed that will target and destroy cyanide-based compounds.

Improved pinch analysis

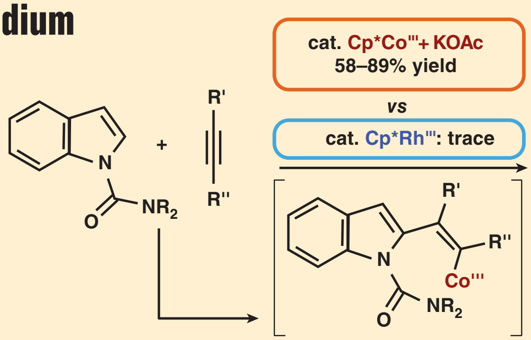
Last month, the national PinCH-Center of the Lucerne University of Applied Sciences and Arts (HSLU: Switzerland; www.hslu.ch/tevt) introduced PinCH 2.0, a new version of its pinch-analysis software, which is now able to optimize processes with either multiple operating cases or batch operation. "The manufacturing processes of chemical, pharmaceutical, food-and-beverage products often feature differing operating conditions or discontinuous production situations. These processes in particular exhibit a considerable potential for improvements in efficiency," explains Beat Wellig, head of the PinCH-Center.

Detecting attograms

Said to be the first significant innovation for electron-ionization (EI) design in decades, the new high-efficiency EI source, developed by Agilent Technologies Inc. (Santa Clara, Calif; www.agilent.com) enables the company's new 7010 Triple Quadrapole GS/MS System to deliver attogram (10^{-18} g) detection limits. Along with lower detection

(*Continues on p. 14*)

Cobalt: a less-expensive and more efficient catalyst than rhodium



One-pot synthesis of *N*-fused indoles

The research group of Shigeki Matsunaga, associate professor at the University of Tokyo (Japan; www.f.u-tokyo.ac.jp/~kanai), in collaboration with Ken Sakata at Hoshi University, has developed a new Co-based catalyst system that outperforms the existing rhodium-based catalyst system for the production of N-fused indol, an important precursor for pharmaceuticals. The catalyst combines Co(III) with acetate ions, which exhibits catalytic performance based on Lewis acidity intrinsic to cobalt. Both components are less expensive and more plentiful than rhodium. With the new Co-based catalyst system, Cp*Co(III) [Cp* = 1, 2, 3, 4, 5-pentamethylcyclopentadienil, $C_5(CH_3)_5^-$], the researchers demonstrated a one-pot synthesis of *N*-fused indole (diagram) far superior to the Rh-based catalyst, Cp*Rh(III). The C2-selective indole alkenylation/annulation sequence proceeded smoothly with a catalytic amount (5 mol%) of $[Cp^*CoIII(C_6H_6)](PF_6)_2$ complex and 20 mol% of KOAc in 1,2-dichloroethane (0.1 M) at 130°C in 20 h, giving pyrroloindolones in 58–89% yield in one pot.

The Cp*Co(III) catalysis was also shown to be suitable for simple alkenylation process of N-carbamoyl indoles, and a broad range of alkynes (including terminal alkynes) to give C2-alkenylated indoles with 50–99% yield.

Matsunaga plans to reduce the catalyst usage and enhance the catalyst life, which could enhance the turnover numbers of the catalyst system.

Microporous vanadosilicate efficiently removes cesium from wastewater

The effective removal of Cs^+ ions from contaminated groundwater, seawater, and radioactive nuclear waste is crucial for public health and for the operation of nuclear power plants. Although several methods for the removal of Cs^+ ions have been developed, there is still a need for better methods.

Now a team of Korean researchers led by professor Kyung Byung Yoon from the Dept. of Chemistry, Sogang University (Seoul; www.sogang.ac.kr) has reported a novel microporous vanadosilicate with mixed-valence vanadium (V^{+4} and V^{+5}) ions, which has an excellent ability to capture and immobilize Cs^+ from groundwater, seawater and nuclear waste. This vanadosilicate also contains hexadeca-coordinated Cs^+ ions, corresponding to the highest coordination number ever observed in chemistry.

The performance of Cs^+ removers is often compared in terms of their distribution coefficient K_d, which is the ratio of the removed amount of Cs^+ ions per amount of remover (in grems) to the amount of residual Cs^+ ions per mililiter of solution.

Among the various sorbents that have been developed, crystalline silicotitanate (CST), currently used at Fukushima, Japan for Cs^+ removal from seawater, has been shown to be quite effective. The Korean researchers claim the porous vanadosilicate material they have developed — named Sogang University-45, SGU-45 — has K_d values much higher than those of CST.

The researchers prepared an oxidized form of SGU-45 material with K^+ ions, K-SGU-45, which has shown a surprising ability to remove Cs^+ from contaminated seawater. K-SGU-45 has also proved to be the most suitable material for the removal of Cs^+ ions from stored nuclear-waste solutions.

The researchers say their work will lead to the syntheses of various vanadium and other transition-metal silicates to capture radioactive nuclides such as Sr^{+2} ions.

(*Continued from p. 12*)

limits, the improved sensitivity offers increased confidence in results at all measurement levels, says the company.

The new EI source creates more than 20 times as many ions as the current generation of EI sources, making it possible to inject smaller sample volumes, scale down preparation volumes, and eliminate time-consuming and error-prone pre-concentration steps.

Fuel cells

VTT Technical Research Center of Finland (Espoo; www.vtt.fi) has developed a pilot-scale (50 kW) power plant based on fuel cells that utilize byproduct hydrogen from the process industry. The power plant has been in operation at Kemira Chemicals Oy's site in Finland since January 2014. The system produces electricity from H_2 generated as a byproduct of a sodium chlorate process at a high electric efficiency, and is the first of its kind in the Nordic countries (see also "Fuel cells move into the CPI plant," *Chem. Eng.*, March 2008, p. 25–27). When scaled up to commercial size, the equipment enables the reduction of energy consumption of the electrolysis process used for sodium chlorate production by 10–20%, says VTT. The Kemira site's annual electricity consumption is approximately 578 GWh. ❑

Demonstration of methane fermentation to lactic acid

What is said to be the world's first fermentation pathway from methane to lactic acid has been demonstrated by Calysta, Inc. (Menlo Park, Calif.; www.calysta.com). The fermentation process begins with an organism that feeds off of methane rather than typical sugar-based feedstocks and, through synthetic biology, has been altered to convert that methane to high levels of lactic acid. This lactic acid production process will be jointly developed under an agreement with biopolymer producer NatureWorks, LLC (Minnetonka, MN; www.natureworksllc.com), who produces polylactic acid for numerous applications, including textiles, consumer plastics and 3D printing.

Although their current work is focused exclusively on lactic acid, Calysta emphasizes that the methane-fermentation platform could be tailored to produce a number of different chemical products, meaning that methane sourced from landfill gas, rice farming or wastewater-treatment processes could be harnessed to produce more valuable end-products. One of the main hurdles to reaching commercial-scale production is overcoming the mass-transfer issues associated with fermentation processes, which usually take place in large, stirred-tank reactors. Through a partnership with Celanese Corp. (Irving, Tex.; www.celanese.com), funded by the U.S. Dept. of Energy (www.energy.gov) and the recent acquisition of Bioprotein A/S (www.bioprotein.no), Calysta is seeking an enhanced loop-bioreactor design that would allow for the process to be more economic and efficient for commercial adoption.

This production process cuts Pt usage in catalytic converters in half

Chemists from the National Institute of Advanced Industrial Science and technology (AIST; Tsukuba City, Japan; www.aist.go.jp) have developed a procedure for making the catalysts used in catalytic converters for treating the exhaust from diesel engines. The process, developed with support from a New Energy and Industrial Technology Development Organization (NEDO) project, has the potential to decrease the usage of Pt by 50%, while enabling mass production of the Pt-Pd nanoparticle catalyst.

To make the catalyst, alumina powder is first impregnated using an aqueous solution of a salt of the precious metals with a small amount of

(*Continues on p. 16*)

A two-step process for making graphene

A Korean team has developed a carbon material that is as effective as graphene in applications, such as solar cells and semiconductor chips, using a process that requires only two steps instead of the usual eight.

High-quality graphene is usually manufactured using chemical vapor deposition (CVD). In this method the graphene is manufactured on the board of a metal film that serves as a catalyst. The graphene is made by blowing out a gas called the source gas onto the board. The metal must be subsequently removed and the graphene has to be transported to another board. This method is therefore labor intensive, and there is usually a degradation of the quality of the graphene, with the appearance of wrinkles and cracks.

The Korean team, led by Han-Ik Joh of the Korea Institute of Science and Technology (KIST, Seoul; http://eng.kist.re.kr), Seok-In Na of Chonbuk National University (Jeonju; www.chonbuk.ac.kr), and Byoung Gak Kim of the Korean Research Institute of Chemical Technology (KRICT, Daejeon; www.krict.re.kr) has developed a carbon nanosheet in a two-step process consisting of coating the substrate with a polymer solution and heating it. The team synthesized a polymer with a rigid ladder structure — PIM-1 (polymer of intrinsic microporosity-1) to form the carbon nanosheet. The carbon nanosheet is spin-coated on the substrate using PIM-1 solution with a light green color, and then heat-treated at 1,200°C, leading to a transparent and conducting carbon nanosheet.

The new method allows mass-production of the carbon nanosheets with a high quality, since it bypasses the steps that tend to form defects, such as the elimination of the metal substrate and the transfer of the graphene to another board. ■

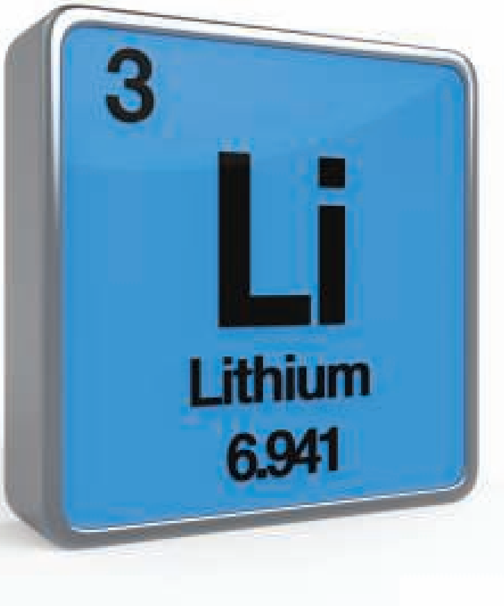
CATALYTIC CONVERTERS

(*Continued from p. 15*)

polyol reducing agent, such as ethylene glycol. Nanoparticles of the metal become deposited on the surface of the dried alumina powder by the polyol reduction reaction in heated nitrogen gas. Finally, the residual polyol is burned off, leaving behind a catalyst system with supported nanoparticles.

Not only does the new catalyst system require less Pt, but it is said to be more resistant to high temperatures. Compared to existing Pt-Pd catalyst systems, the new system exhibits the same, or better performance for the treatment of hydrocarbons from exhaust, achieving a 95% cleaning efficiency at temperatures above 250°C. The high performance is believed to be due to the small size of the nanoparticles (about 3-nm dia.), which are insulated from the detrimental effects of sintering.

SPOTLIGHT ON LITHIUM



Lithium producers are developing process technology to supply the anticipated growing demand

A huge growth in demand for lithium compounds is expected when automotive manufacturers start mass producing hybrid, plug-in hybrid and electric vehicles using lithium-ion batteries. In anticipation of the expanded business, many minerals-processing companies have been developing technologies for processing lithium from ores or brine into battery-grade (high-purity) lithium carbonate or lithium hydroxide.

Changing market

For many years, the majority of lithium compounds have been used in the production of ceramics, glass and primary aluminum. They have also been used in mobile phones, computers, rechargeable power tools, electric motors for electric bicycles, and alloys to increase strength-to-weight ratios in aerospace and motorsports applications. Lithium carbonate has also been used in medicine for the treatment of several ailments, including bipolar disorder.

Today, the two biggest markets for lithium compounds are in the manufacture of lithium ion batteries for electric vehicles and in energy storage for smart grids. Market reports predict that world lithium demand will increase by a factor of 2.5 between 2010 and 2020. For example, a recent report by signumBOX (Santiago, Chile www.signumbox.com) predicts that global lithium demand will grow at a base rate of 6% in 2014 from 2013 rates. That increase will be primarily due to an increase in demand from the battery industry, which is projected to grow at a base rate of 11.2% in 2014 from 2013, and increase in subsequent years.

Properties and compounds

Lithium is ideal for use in batteries because it has the highest electric output per unit weight of any battery material. Lithium-ion batteries feature high energy density, high voltage, no memory effect, and a flat discharge voltage. They have a specific energy density of 100–265 Wh/kg, volumetric energy density of 250–730 Wh/L, and specific power density of 250–340 W/kg. Nominal cell voltage is about 3.2–3.6V.

Minerals-processing companies usually produce lithium carbonate (Li_2CO_3, of at least 99.5% purity), or lithium hydroxide (LiOH, of 99.99% purity), which are used in the manufacture of most lithium-ion battery cathodes.

Handheld electronics mostly use lithium-ion batteries with lithium cobalt oxide ($LiCoO_2$) cathodes, which offer high energy density, but have a relatively short life span and entail safety risks. Lithium iron phosphate (LFP; $LiFePO_4$), lithium manganese oxide (LMO; $LiMn_2O_4$) and lithium nickel manganese cobalt oxide (NMC; $LiNiMnCoO_2$) offer lower energy density, but longer lives and greater safety. The trend in lithium-ion batteries is now to use a lightweight lithium/carbon negative electrodes and LFP positive electrodes.

However, NMC seems to be a leading contender for automotive applications. Lithium nickel cobalt aluminum oxide NCA; $LiNiCoAlO_2$) and lithium titanate (LTO; $Li_4Ti_5O_{12}$) are aimed at niche applications.

Lithium reserves

Lithium compounds are produced either from lithium-containing brines or from lithium-bearing minerals. The most common brine deposits are saline desert basins, also known as salars. Brine deposits account for about 66% of global lithium resources and are found mainly in the salt flats of Chile, Argentina and Bolivia.

Most lithium minerals originate from lithium pegmatites — igneous rocks formed by the crystallization of volcanic magma that contain the mineral spodumene ($Li_2O{\cdot}Al_2O_3{\cdot}4SiO_2$ — about 8% Li_2O), which is the main mineral source for the commercial production of lithium compounds. Known pegmatite deposits are in Alaska, Northern Ontario, Quebec, Ireland and Finland, but the largest current spodumene operation is located in Greenbushes, 250 km south of Perth in Western Australia.

Production processes

Production of lithium compounds from brines has usually been seen as more cost-effective than production from spodumene. Brines usually require evaporation in ponds, which may take more than a year. There are minerals-processing companies that claim to have found methods of eliminating the need for evaporation and thus reducing the time it takes to produce lithium compounds from several months to a few hours.

However, lithium concentrate is considerably higher in pegmatites than in brines, making pegmatite deposits economically viable and able to compete with brine deposits. Since hard-rock lithium deposits are found worldwide, in contrast to the brine deposits, a large number of exploration projects for hard-rock lithium deposits has been initiated in various parts of the world. Exploiting local lithium-mineral resources puts the industry in a stronger and less dependent position.

Processes for producing lithium carbonate from lithium-containing ores typically used thermal treatment — at a temperature of about 1,100°C — of the normal, α-spodumene with a monoclinic crystal structure, transforming it into β-spodumene which crystallizes in the tetragonal system and which can be solubilized by acid. The β-spodumene is sulfated in acid in a kiln, producing water-soluble lithium sulfate. The lithium sulfate goes through one or more leaching tanks. Limestone, lime and sodium carbonate are added to the product of the leach to adjust the slurry's pH, thus precipitating certain impurities such as iron, aluminum, magnesium and calcium. The residue is then separated, leaving a concentrated solution of lithium sulfate. The lithium sulfate is then treated with a concentrated sodium carbonate solution, thus precipitating lithium carbonate.

However, those processes are relatively inefficient in the removal of impurities remaining in the pregnant leach solution, and this is critical when producing battery-grade lithium carbonate. Also, in those processes, several byproducts are wasted.

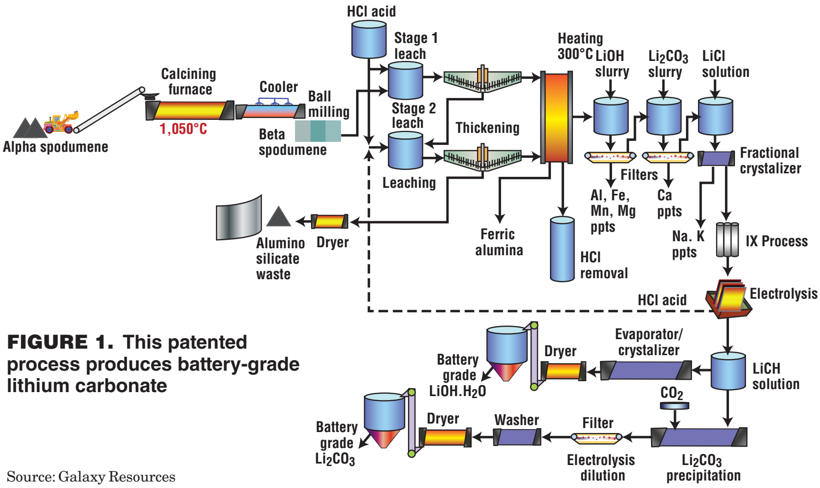


FIGURE 1. This patented process produces battery-grade lithium carbonate

Source: Galaxy Resources

Several minerals-processing companies have developed technologies to address these problems.

One example is Galaxy Resources Ltd. (Perth, Western Australia; www.galaxyresources.com.au), which has developed and patented a process for producing battery-grade lithium carbonate. The process (Figure 1) comprises the following operations:

- Calcining a α-spodumene to produce β-spodumene
- Sulfating the β-spodumene at elevated temperature
- Passing the sulfated β-spodumene through a leach step in which lithium sulfate is leached in water
- Passing the pregnant leach solution to a series of impurity removal steps in which iron, alumina, silicates and magnesium are precipitated and removed
- Adding sodium carbonate to the previous step by which calcium is precipitated
- The product of the previous step is passed to an ionßexchange step in which residual calcium, magnesium and other remaining multivalent cations are removed
- Passing the purified product of the previous step through a lithium carbonate precipitation step in which sodium carbonate is added to produce precipitated lithium carbonate and a sodium sulfate mother liquor
- Passing the mother liquor to an anhydrous sodium sulfate recovery process, from which a solid sodiumßsulfate product is obtained and a portion of the sodium sulfate mother liquor is also recirculated to the leach step

Galaxy's process has been used to produce battery-grade lithium carbonate at its Jiangsu Lithium Carbonate Plant in the Yangtze River International Chemical Industrial Park of the Zhangjiang Free Trade Zone in China's Jiangsu Province. The lithium originates from Galaxy's Mt. Cattlin mine at Ravensthorpe, Western Australia. However, last May, Galaxy sold the Jiangsu plant to Sichuan Tianqi Lithium Industries, part of Chengdu Tianqi Group (Chengdu, China; www.tianqigroup.cn).

Galaxy Resources will now focus its efforts on the Sal de Vida lithium brine and potash project in Argentina. Galaxy's managing director, Anthony Tse, says the company will continue to retain significant exposure to the lithium sector through the Sal de Vida lithium brine project with Mt. Cattlin in Western Australia and James Bay in Quebec.

Last year, Sichuan Tianqi Lithium Industries purchased Australian company Talison Lithium Pty Ltd. (Perth; www.talisonlithium.com), which produces lithium concentrate at its project located in the town of Greenbushes. The Chengdu Group now controls about a third of global lithium supply. At full capacity, the Jiangsu plant will produce 17,000 metric tons (m.t.) of battery-grade lithium carbonate per year.

Another producer of lithium and lithium compounds, Rockwood Holdings, Inc. (Princeton, N.J.; www.rocksp.com), has created a joint venture with Sichuan Tianqi Lithium Industries, giving Rockwood a 49% ownership interest in Talison Lithium. The purchase was announced by Rockwood Lithium (Frankfurt, Germany; www.rockwoodlithium.de), a subsidiary of Rockwood Holdings. Rockwood Lithium produces lithium carbonate at the Salar de Atacama, Chile, and in Nevada.

Rockwood Holdings and Sociedad Quimica y Minera de Chile (Santiago, Chile; www.sqm.com), which both operate on the country's Salar de Atacama, are two of the world's leading lithium producers.

Another Australian company that has developed and patented a process to produce battery-grade lithium carbonate and lithium hydroxide is Reed Resources Ltd. (Perth; www.reedresources.com). Its process (Figure 2) utilizes the electrolysis of a lithium chloride solution obtained from either a spodumene ore or concentrate, or from brines. The spodumene comes from the Mt. Marion Lithium Project in Western Australia, which is located about 40 km south of Kalgoorlie and jointly owned by Reed Resources (70%) and Mineral Resources Ltd (Perth; www.mineralresources.com.au), a mining service, processing and commodities production company.

The Reed Resources process (Figure 2) comprises the following steps:

- Preparing a process solution from the lithium containing material, where the α-spodumene is calcined to produce β-spodumene
- Passing the process solution to a series of impurity removal steps providing a fairly purified lithium chloride solution
- Passing the purified lithium chloride solution to an electrolysis step thereby producing a lithium hydroxide solution
- Carbonating the lithium hydroxide solution by passing compressed carbon dioxide through the solution, thus producing a lithium carbonate precipitate

A similar process is employed by

Nemaska Lithium Inc. (Quebec, Canada; www.nemaskalithium.com), which is also focused on producing high-purity lithium carbonate and hydroxide. The company has filed patent applications for its electrolysis-based process. It is developing the Whabouchi lithium deposit, located about 300 km from Chibougamau, Quebec, which is estimated to be one of the richest and highest-grade lithium deposits in the world. Nemaska's production plant, located in Salaberry-de-Valleyfield, Quebec, will have an average capacity of 500 m.t./yr.

Unlike more traditional processes that use soda ash to produce lithium carbonate for the production of lithium hydroxide, the company's electrolysis-based process produces lithium hydroxide directly, eliminating a greater amount of impurities. The process nearly eliminates the use of soda ash, improving the process' economics.

Construction of the mine is scheduled to start in mid-2015, and the start of concentrate production and commissioning is scheduled for the fourth quarter of 2016.

Reed Resources managing director Chris Reed says the main difference between Reed's process and Nemaska's is that Reed uses hydrochloric acid and as such, Reed's process is a traditional chlor-alkali process. Hydroxide is the primary product, it is only necessary to bleed carbon dioxide into the LiOH liquor to drop out lithium carbonate, he says.

Also in Quebec, RB Energy, Inc. (Vancouver, British Columbia; www.rb-e.com) has announced it has achieved continuous production of battery-grade lithium carbonate at its Quebec Lithium operation located at La Corne, Quebec. The company aims to achieve commercial production levels (20,000 m.t./yr) by the end of this year. "We are now focused on increasing production levels, firstly toward meeting the initial shipping volumes required by our offtake partner Tewoo, secondly to reach commercial production levels and finally, to realize the design production threshold of 20,000 m.t./yr, says Reed."

Also, Western Lithium Corp. (Vancouver, B.C.; www.westernlithium.com) is planning to operate a lithium carbonate demonstration plant by the end of this year at its Kings Valley, Nev. lithium deposit, one of the world's largest known lithium deposits. The reserve base supports an annual production of 26,000 m.t. of lithium carbonate.

Production of high-purity lithium carbonate, based on different lithium raw materials, is also the aim of Outotec Oyj (Espoo, Finland; www.outotec.com). Outotec has de-

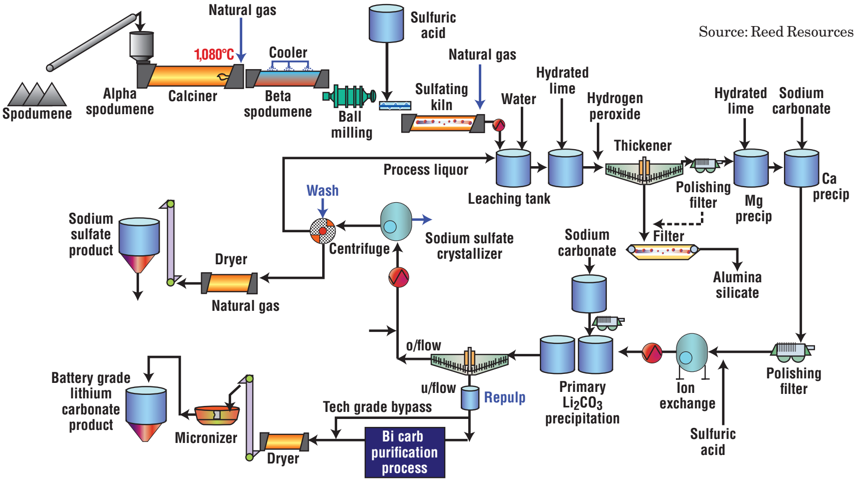


FIGURE 2. Reed Resources' patented process that produces battery-grade lithium carbonate and lithium hydroxide

veloped processes to obtain high-purity lithium carbonate from both, spodumene ore, and from lithium-bearing brines. Its process to obtain lithium carbonate from spodumene ore is alkaline. After crushing, separation, grinding and flotation, the ore is filtered in the company's automatic pressure filters. It is then calcined and subjected to pressure leaching and hydrocarbonation in alkaline media. After dewatering, impurity removals and crystallization, it is filtered in vacuum belt filters into lithium carbonate.

The company's processing of brine comprises: pretreatment, boron solvent extraction, calcium and magnesium precipitation and purification, lithium carbonate precipitation, dewatering, and filtration to obtain high-purity lithium carbonate. Byproducts include potassium and sodium salt, calcium and magnesium precipitates, and boric acid.

A few companies claim to have developed methods to obtain lithium compounds from brines without the need for evaporation ponds, or drastically reducing the area required for the ponds, and drastically reducing the processing time from many months to less than 24 hours.

One of these companies is Tenova Bateman Technologies Australia (Perth; www.tenovagroup.com). The company has developed a solvent extraction, combined with a membrane technology for the pretreatment of the initial brine. The loaded solvent is stripped using a strong mineral acid, and the product solution is the lithium derivative of that stripping acid. This results in reducing the area needed for a commercial plant and also reduces the residence time. The application of different stripping acids can also diversify the product line of such a facility.

South Korean steel-maker Posco (Pohang, South Korea; www.posco.com), which also produces lithium compounds, claims to have also developed a technology to obtain lithium from brines by chemical means, eliminating the need for evaporation ponds, and reducing the time to obtain lithium from many months to a few hours.

Simbol, Inc. (Pleasanton, Calif.; www.simbolmaterials.com), also claims to have developed a separation technology capable of extracting high-purity lithium carbonate from hydrothermal brines, using a reverse osmosis process that eliminates the need for solar evaporation.

The great effort by many companies to develop technologies for producing lithium compounds of high purity is a response to the prediction of a market boom for lithium compounds by several market analysts. If the predicted market expansion does in fact materialize, it will find businesses well prepared. ■

Paul Grad

SOFTWARE FOR THE HUMAN ELEMENT

New software makes plant personnel more effective by providing quality, actionable information

New software tools address common issues, such as disorganized data and a streamlined workforce, through the use of simplified methods of presenting information, alerts and suggested actions. These tools are designed to increase human reliability and make chemical processing facilities safer and more reliable and more efficient.

Improving safety

"One of the biggest issues for processors is that information regarding safety, instrument reliability and procedures is all locked into different silos," says Andrew Soignier, vice president, Chemical, Oil and Gas Solutions with Ventyx, an ABB company (Houston; www.ventyx.com). "This makes the information inconsistent. In addition, most of the times the reports and information generated by disparate systems are very backward looking."

He says key performance indicators (KPIs) and metrics in processing plants are often weeks old by the time the information is analyzed. "The decisions that were required at the time of the risk are in the past tense now," says Soignier. "When it comes to risk management, people need information right now, in realtime."

One of the key areas of a process-safety-management solution should be managing operations with confidence and giving people a true look into their operational risks as those risks occur, continues Soignier. "Where's the vulnerability coming from right now? What decisions are people making currently that could affect the process and increase their risk of a hazardous event?

"A solution needs to provide key information and decision support based upon the current, at-the-moment risks and present prioritized available actions that optimize activities and reduce those risks," he explains.

This, he says, can be done by giving operators visibility of all of the information that is currently spread across multiple systems and various spreadsheets in a realtime environment, accompanied by prioritized suggested actions. "The key is not just another tool that tells them that they have a problem. Rather, the key is in the action piece and tying this action into a procedure that can be done to mitigate the risk," explains Soignier. "It removes the guesswork and provides timely actions, thus simplifying risk reduction."

The company's Process Safety Management solution does this. The software was designed to give chemical, and oil-and-gas companies an enterprise-wide view of process-safety risks, enabling clients to track deviations to safeguards, evaluate the risks and prioritize corrective actions in a timely manner. The tool takes safety beyond traditional instrumented monitoring functions and extends it into everyday operations, maintenance and management. It provides situational awareness and visibility of managed risks, contextual information to facilitate decision support and procedural automation of work processes (Figure 1).

Similarly, PAS (Houston; www.pas.com) offers an Operations Management Solution that is designed to help improve the presentation of the information that goes to the frontline operators so that they may more easily make good decisions and keep the plant running safely, says Mark Carrigan, vice president of marketing with PAS.

"One of the areas that has been lacking in software tools in the past is how we presented information to the operators regarding everything from the design of the graphics to the alarm systems to managing the process limits that the operators had to deal with," he says. "We, as software developers, didn't always take into consideration the human element and all that the operator has to deal with at any given moment. We were throwing tons of information and data at operators without a lot of context and it made it really hard for them to figure out what's going on inside the plant and keep the plant running safely."

But all that is changing with the company's PlantState Suite of software. "What we did here is optimize the operator cockpit so they get really good information at the right time to keep the plant running safely," explains Carrigan. "The operator is key to overall plant safety and this [software] presents the information he needs in such a way that it can actually be used to make up-to-the moment decisions."

The PlantState Suite includes four solutions: High-Performance Human-Machine Interface, Alarm Management, Boundary Management and Control Loop Performance.

"In the past, the graphics were schematics and drawings with numbers representing current values, which isn't really the best way to convey process health information," admits Carrigan. "This meant the operator usually waited for alarms to know that the process was out of control and that made him reactive, rather than proactive." Instead, PAS's new solution transforms these operator displays from the traditional schematic style to an intuitive visualization of data by enabling at-a-glance situation

Ventyx

FIGURE 1. **Ventyx's Process Safety Management solution was designed to give chemical and oil-and-gas companies an enterprise-wide view of process safety risks, enabling clients to track deviations to safeguards, evaluate the risks and prioritize corrective actions in a timely manner**

awareness through the use of pattern recognition, properly grouped information and by incorporating decision support information within the displays, such as alarm limits and alarm documentation.

In the past, operators were bombarded with alarms, which often caused them to miss important alarms. The new alarm-management tool improves the alarm system so that operators get the right alarm at the right time to help them figure out what's going on and respond to avoid upset conditions. Boundary management is an extension of alarm management. This tool serves as a central repository for operational boundary limits. It dynamically monitors constraints in realtime for exceedance notifications. Also, control-loop optimization provides an analysis of both regulatory and advanced control loops to identify process interactions and variability, hardware issues or poor tuning. It continuously monitors and prioritizes loops based on the greatest benefits to the facility.

"The solutions make the plant more effective and efficient by making people in the plant more reliable because they now have an easier way to view, manage and interpret data," says Carrigan. "Optimizing the human/automation relationship leads to better management and increased safety."

Another major safety issue for chemical processors, which can now be handled thanks to advances in software products, is overpressure protection, says Ron Beck, director of product marketing for aspenONE Engineering at Aspen Technology (Burlington, Mass.; www.aspentech.com). "These overpressure incidents are usually due to the overpressure protection systems not being adequate," says Beck. "And one of the biggest causes of this is incorrect data transcription. Typically overpressure protection analysis has been done by hand with calculations or on spreadsheets. People copy data from modeling tools for use in these methods, but often make mistakes while doing so. Another common mistake is that accurately sizing safety relief valves requires insight into the entire, interconnected system. However, finding this information is difficult because most facilities manage pressure safety valves using a list, which prohibits a view of the system as a whole."

As a result, Aspen Technology introduced aspenONE Version 8.6 software with an expansion into process-safety analysis with expanded overpressure protection capabilities. The software offers the ability to design and rate safety relief valves, as well as run fire-analysis scenario calculations that take into account latent heat and temperature change. Rupture disk sizing has also been added.

In addition, aspenONE V8.6 tackles dynamic modeling of compressors. "Dynamic modeling is the best way to ensure the health and safety of the compressors in a facility, but to the typical process engineer, dynamic modeling seems difficult and scary. So we've developed an easier-to-use dynamic model for this function," says Beck. "Our goal is to provide more accessibility to difficult-to-use tools by providing a number of different templates and scenarios."

The Activated Dynamics Analysis automates dynamical modeling with a single button click to speed model setup and enable more process engineers to perform compressor operability screening (Figure 2).

Aspen Technology

FIGURE 2. **The addition of Activated Dynamics Analysis to aspenONE Version 8.6 automates dynamical modeling with a single button click to speed up model set up and enable more process engineers to perform compressor operability screening**

Reliability and efficiency

Software that makes it easier for operators and technicians to prioritize actions is key to increasing reliability and efficiency. "Processing plants no longer have as many skilled people as they used to, so they are constantly faced with the challenge of having to do more with the people they do have," notes George Buckbee, general manager at ExperTune, a Metso company (Hartland, Wisc.; www.expertune.com). "For this reason software solutions that go beyond automated monitoring to include automated diagnostics and, more importantly, automated prioritization and recommendations are critical.

"There are so many issues at most chemical plants that there's never a chance to address everything, so prioritization according to safety, economic and technical factors is of utmost importance," Buckbee explains. "If I can only work on one thing today, what one thing should it be? Our PlantTriage solution always looks for that answer."

Metso's ExperTune PlantTriage software performs continuous assessments of the performance of model predictive controls (MPC) to improve the performance of the whole control system, from advanced control all the way down to the individual instruments and valves. In addition to a detailed assessment of MPC performance, the latest version now presents the results in a new, more user-friendly browser interface and allows users to drill down directly from MPC monitoring to find root causes that may be outside of the MPC structure itself.

Buckbee adds that the latest version can automatically generate custom newsletters for individual users. "For example, someone who's responsible for controller tuning gets a newsletter delivered to his email box that may say: 'These five loops need to be tuned. Here's what the new tuning constants should be.' This really streamlines the work process and drives the work directly to the individual who needs to do it," he says.

"We like to say that PlantTriage is like having a 100-year-old, experienced engineer who never sleeps.

Opto 22

FIGURE 3. **The groov, which allows access to a facility's automation system from a mobile device, makes mobile devices more accessible. It allows users to build mobile operator interfaces — customized mobile apps — and securely monitor and control just about any automation system and equipment**

It provides depth of experience and is always looking after the process and can identify where things might go wrong and notify engineers about what needs to get done and when to prevent that from happening," says Buckbee.

Solutions for mobility are also helping to increase productivity by giving people the power to control operations from wherever they are and to keep track of maintenance tasks and procedures while in the field. Used properly, mobile devices and related software applications make people's jobs easier, more efficient and more effective, according to Steve Elliot, an industry solutions executive with Ventyx. Ventyx's Mobile Work Management solution is a fully integrated, end-to-end suite of applications that enhance work performance by automating field force operations. With mobile work management, field personnel can perform the right job, at the right time, with the right resources. This solution is for asset-intensive industries that need to address strategic issues like improving enterprise-wide asset utilization, asset performance, asset maintenance strategies and asset field service. It includes automating work processes to safely and efficiently perform inspections, maintenance and repairs.

Other tools, such as the groov, which allows access to a facility's automation system from a mobile device, from Opto 22 (Temecula, Calif.; www.opto22.com) are also helping to make mobile more accessible. Groov allows users to build mobile operator interfaces — customized mobile apps — and securely monitor and control just about any automation system and equipment, according to David Engsberg, regional sales engineer with Opto 22 (Figure 3). To use the tool, all that is needed is an Internet browser. To build an interface, users just drag and drop from a library of touchscreen-ready gadgets, then browse the tag server and tag the gadget with an input, output or variable from the system or equipment. There is no programming and no coding needed. Groov works on any device from an iPod touch all the way up to a web-enabled big screen television. Graphics, buttons, labels, images, live video and trends all scale to fit the device on which it's being viewed.

"There are no limits on this system," notes Engsberg. "It lets you build the system as large or as small as you want for as many users as you want. Since it's a webserver, if a user builds an app and adds a dial or moves the screen around based on an operator change and saves it to the groov server, the deployment happens automatically. This increases reliability and efficiency in the facility."

While no tool is foolproof, today's software provides easy-to-use, easy-to-read and truly helpful information and data to assist plant engineers in keeping the plant running safer and smoother. ■

Joy LePree

Maintenance Equipment

Emerson Industrial Automation

Elos Fixturlaser

Crystal Instruments

No re-measurement is required with this shaft-alignment tool
The EVO (photo) is an all-digital shaft-alignment tool with an adaptive user interface, which shows how a misaligned machine must be moved vertically or horizontally by adding or removing shims at the machine's feet. The EVO requires no re-measurements in between horizontal and vertical adjustments during the alignment process. The horizontal adjustment is carried out with real values displayed during the entire process. The units are fitted with a 30-mm charge-coupled-device (CCD) detector that enables accuracy and precision in measurements. The EVO is compact — it can be held in one hand — and simple to operate, featuring a 5-in. color touchscreen. — *Elos Fixturlaser AB, Mölndal, Sweden*
www.fixturlaser.com

Route-based and onsite vibration measurement and analysis
The CoCo-80 Vibration Data Collector (photo) features a user interface that is specially designed for use in vibration-analysis and machine-condition-monitoring applications. Included along with standard vibration-data functionalities, the CoCo-80 includes route-setup capabilities, robust measuring tools and data management and backup options. The collector also has both route-based data collection and on-site measurement functions. The route-based mode includes overall readings, as well as time waveform and spectrum data. The onsite measurement mode conducts a number of tests in addition to data collection, including bump, coast-down/run-up and balancing tests. A combination of Ethernet interface and remote software allows for distributed measurements with multiple units. Remote monitoring of CoCo-80 units is possible through wireless communication. — *Crystal Instruments Corp., Santa Clara, Calif.*
www.crystalinstruments.com

This automatic sliding motor base maintains belt tension
The Browning Tenso-set Series 600 horizontal sliding motor base (photo) automatically maintains belt tension for extended periods of time and also allows for very quick belt changes. This device reduces the frequency of re-tensioning services and helps maintain efficiency by preventing belt slippage. The Series 600 operates like a standard motor base, utilizing a jackscrew to adjust and hold tension on the belt. However, the new design includes a coil spring inside the screw housing that pushes against the carriage to maintain tension as the belt wears or seats itself further into the sheave groove. Featuring heavy steel construction, this motor base is sized to fit National Electrical Manufacturers' Association (NEMA) frame sizes 56 and 286, but custom sizes can be produced for specific applications. — *Emerson Industrial Automation, St. Louis, Mo.*
www.emersonindustrial.com

SKF USA

A portable IR thermometer with remote and direct-contact modes
The new TKTL 40 portable infrared (IR) thermometer (photo) enables safe and efficient measurement of

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

machine temperature at a distance, and allows users to take photos and videos showing the actual measured surface temperature from the equipment. These readings can then be reviewed and shared by maintenance technicians and operators. The detection of abnormal or high temperatures ultimately can help prevent problems and unplanned machinery downtime associated with potential lubricant or bearing damage. The TKTL 40 is easy to use by simply aiming and pulling the trigger. The thermometer performs with a distance-to-spot ratio of 50:1 for accurate surface-temperature readings of very small areas, even at long measuring distances. Features of the unit include a backlit display, dual-laser sighting, a K-type probe connection (for direct-contact temperature measurement) and a bright LED illuminator for visibility, even in poorly lit environments. A data-logging function can be engaged to track temperature changes over time. — *SKF USA, Inc., Lansdale, Pa.*
www.skfusa.com

Manage and prioritize spare-parts inventory with this system
This company's specialized software system for identifying and managing critical spare parts and machinery is designed to fill in gaps in typical enterprise-resource-planning (ERP) and computerized maintenance-management systems. The software provides appropriate replenishment-level algorithms (incorporating lead-time, usage and other parameters) for spare parts inventory, and also manages controls for repair and warranty parts. When users upload data about existing inventory, parts and machines are associated and organized based on machine-criticality levels, allowing for prioritization of what parts need to be stocked, while also identifying any obsolete or redundant inventory. Additionally, probability of part failure is considered, enabling proactive scheduling for predictive maintenance tasks. — *MaxUp Advantage, Las Vegas, Nev.*
www.maxupadvantage.com

GTI Predictive Technology

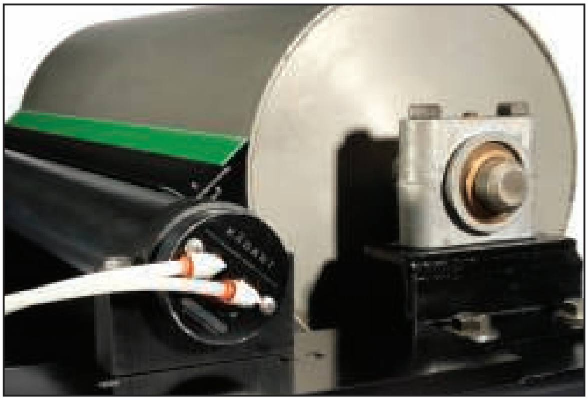
A predictive maintenance solution for iPad tablets
VibePro6 (photo) is a predictive maintenance system that is designed specifically to run on an Apple iPad tablet. Providing functionality for vibration analysis, dynamic balancing, IR thermography and laser shaft alignment in a single device, VibePro6 is a more affordable solution than other comparable systems on the market, says the company. The vibration-analysis software is specifically designed to communicate directly to the alignment component and any reports generated from the shaft laser-alignment unit can be instantly accessed. VibePro6 also offers efficient documentation. Full reports on corrective actions can be archived — IR images, photos, videos and other data can be integrated into these reports. — *GTI Predictive Technology, Manchester, N.H.*
www.gtipredictive.com

Remote site monitoring, even without wireless network access
The ICX30-HWC Industrial Cellular Gateway (photo) allows remote-site access for device monitoring where wireless-network capabilities may not be available. The ICX30-HWC provides secure wireless Ethernet and serial connectivity to remote devices and equipment over 3G cellular-service networks. Compatible with cellular networks worldwide, the ICX30-HWC is appropriate for use in a number of industrial applications, including programming, maintenance tasks, remote data collection, location-based monitoring and supervisory control and data acquisition (SCADA). — *ProSoft Technology, Inc., Bakersfield, Calif.*
www.psft.com

ProSoft Technology

New interface features for this data-management software
The new features of this company's Plant Resource Manager (PRM) version R3.12 software provide robust central-management techniques for large amounts of data from plant-monitoring and control devices. The centrally located remote monitoring of field-device status provided by PRM R3.12 facilitates more efficiency in maintenance and diagnostics in many process industries, such as oil, natural gas, petrochemicals, chemicals, power, iron and steel, and pulp and paper. Self-diagnostic information (namely, failure, check-function, out-of-specification and maintenance-required data) is displayed in an intuitive format, enabling maintenance personnel to quickly prioritize actions. Also, network functions have been enhanced to include narrow-band wireless and satellite communications. — *Yokogawa Corp. of America, Newnan, Ga.*
www.yokogawa.com/us

This toolkit automates bearing commissioning and maintenance
This company's Automated Commissioning System is a toolkit (photo, p. 29) of intelligent programs that aid in commissioning and maintenance tasks for magnetic bearing systems. The unit's computer-based automation scheme guides users through a highly structured sequence of commissioning procedures, decreasing the time required for typical hands-on commissioning. The Automated Commissioning System also delivers automatic collection and archiving of essential data, which reduces the time required for planned maintenance. Capable of monitoring machine progress to rapidly identify deg-



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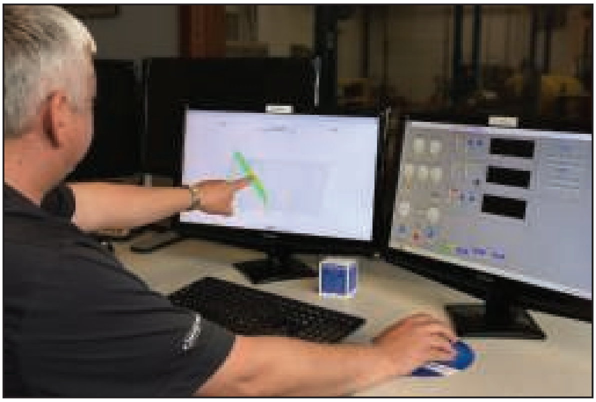


Waukesha Bearings

radiation, the system provides automatic checks after maintenance and consistent tuning for repeat units. Additionally, the Automated Commissioning System quickly records measurements, and can collect multiple measurements within a few seconds to ensure an accurate assessment. — *Waukesha Bearings Corp., Pewaukee, Wisc.*
www.waukbearing.com

Achieve uniform belt and roll cleaning, even in small spaces

The Verikleen and VeriLite (photo) roll-cleaner assemblies are compact, lightweight and rugged devices designed to remove contaminants, such as dirt, scale, coatings and adhesives, from belts and rolls. The proprietary, self-pivoting blade holder provides precise blade loading against the belt or roll, resulting in uniform cleaning and improved line productivity. Designed specifically for applications where installation space is limited, lightweight-alloy construction allows for these ultra-compact assemblies to be used in applications where traditional roll cleaners are not feasible, according to the company. — *Kadant Inc., Westford, Mass.*
www.kadant.com ■

Mary Page Bailey

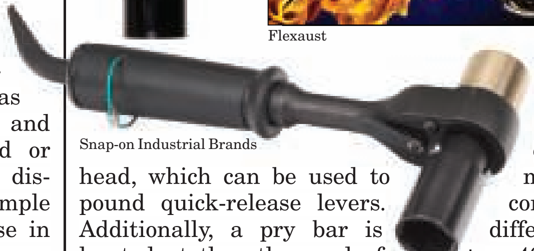
AUGUST
New Products

FilterSense

Sierra Monitor

Flexaust

Dymax



Snap-on Industrial Brands

Monitor hydrogen sulfide in high-temperature environments

The 5100-15-IT Intelligent Solid-State Hydrogen Sulfide Gas Detector (photo) utilizes metal-oxide semiconductor (MOS) sensor technology to accurately monitor hydrogen sulfide in environments where temperatures are extremely high. This network-enabled gas detector has a variety of output formats, and features a user-friendly fixed or scrolling eight-character LED display, intuitive menus and simple calibration procedures. For use in hazardous areas, cast-aluminum or 316 stainless-steel enclosures are available. — *Sierra Monitor Corp., Milpitas, Calif.*
www.sierramonitor.com

An exhaust hose for very high-temperature operations

The Flex-Lok 570 high-temperature exhaust hose (photo) is a coated fabric hose designed for exhaust venting and welding fume extraction. The mechanically crimped hose is constructed from a para-aramid fabric locked around a coated steel wire. This lightweight hose is flame-retardant, puncture-resistant, features high tensile strength and can operate at temperatures from –40 to 570°F. Hoses are offered with diameters ranging from 4 to 18 in. and standard 25-ft lengths. — *Flexaust Inc., Warsaw, Ind.*
www.flexaust.com

Use this ratchet tool for erecting and disassembling scaffolding

The Williams Scaffolding Ratchet (photo) is intended for applications where scaffolding must be erected for work at an elevated level. Featuring a 36-tooth gear with 10 deg of engagement, this tool can easily engage the posts, fastener and clamps on scaffolding. The ratchet comes with a 1/2-in. drive-pinned 7/8-in. six-point socket. Opposite of this socket is a bronze hammer head, which can be used to pound quick-release levers. Additionally, a pry bar is located at the other end of the ratchet to aid in scaffolding disassembly. A tethering device prevents dropped tools. — *Snap-on Industrial Brands, Kenosha, Wisc.*
www.snaponindustrialbrands.com

These particle sensors are designed for extreme conditions

The PS 10 particulate-matter flow and emissions sensor (photo) is engineered for harsh processes with high temperatures and pressures, such as coal gasification, fluidized-bed reactors, kilns and other combustion or incineration processes. Temperature ratings up to 1,600°F and pressure ratings to 1,000 psi are available. There are no active electronics in the sensor housing itself, providing high reliability. The sensor is mounted remotely to electronic control units that apply advanced digita-signal processing to allow for operation even in extreme conditions. Monitoring applications include particulate emissions from fabric filters and particulate flow in process pipes. — *FilterSense, Inc., Beverly, Mass.*
www.filtersense.com

A versatile curing solution for larger light-curable parts

The BlueWave LED Flood System (photo) for light-curable materials provides intensity, uniformity and repeatability in the curing process. With the system's instant on/off capability, there are no mechanical shutter components, no warmup requirements, faster exposure cycles and lower maintenance costs, says the company. The availability of three different irradiator heads (365, 385 or 405 nm) gives users the ability to optimize the curing process. Additionally, the BlueWave LED system features a 5 by 5-in. active area for curing larger parts and reduced curing times. — *Dymax Corp., Torrington, Conn.*
www.dymax.com

These acrylic flowmeters have interchangeable scales

This company's 6A02 acrylic flowmeters have interchangeable direct-reading scales that are available for any one of the following: water, argon, oxygen, carbon dioxide, nitrogen and helium. Scales are mounted at the front of the flow body and are positioned and secured by a clear front-plate held in place by four screws. A low-hysteresis, multi-turn needle valve is also included. Dual scales display flowrates in both metric and English units. These flowmeters can operate up to a maximum temperature of 150°F and a maximum pressure of 6.89 bars, with an accuracy of ±3%. — *Dakota Instruments, Inc., Orangeburg, N.Y.*
www.dakotainstruments.com

These systems recycle metalworking coolants

HydroFlow Coolant Recycling Systems (CRS; photo, p. 31) can recycle any water-miscible fluid to its maximum potential, thus minimizing disposal requirements and reducing

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

Eriez

NewAge Industries

usage of the fluid concentrate. These systems are available in four different sizes, the largest of which will meet the recycling requirements of facilities with up to 10,000 gal of total sump capacity. Using a high-speed centrifuge, a Hydroflow CRS promotes the removal of free and mechanically mixed tramp oils, bacteria and particulate matter from metalworking coolants. Larger models include two dirty and two clean tanks for facilities where two different metalworking fluids are in use. — *Eriez, Erie, Pa.*
www.eriez.com

These PVC hoses are reinforced with steel to resist crushing

The Vardex PVC hose is made of clear, chemical-resistant polyvinyl chloride (PVC) and reinforced with spiral steel wire for durability. Capable of handling both pressurized and vacuum environments, potential applications for Vardex hoses include: chemical transfer; air supply; coolant feed; floor-cleaning; material handling; water feeds and discharge; spray systems; and food-and-beverage supply lines. Vardex's non-toxic PVC construction provides resistance to corrosion and abrasion, but the steel internals impart strength. These hoses resist kinking, crushing and collapse, even in full-vacuum conditions. Offering a bend radius of approximately four times its diameter, these hoses are especially useful in applications where many bends and turns are involved. Vardex hoses are available in nine sizes, with a variety of compatible fittings and clamps. — *New Age Industries, Inc., Southampton, Pa.*
www.newageindustries.com ■

Mary Page Bailey

CHEMICAL ENGINEERING
FACTS AT YOUR FINGERTIPS
Department Editor: Scott Jenkins

Activated Carbon

Sorbent materials are used commercially for bulk separation, as well as purification of both liquids and gases. This one-page reference provides manufacturing and application information on the most widely used industrial sorbent material — activated carbon.

Four types of generic sorbents have dominated industrial adsorption: activated carbon, zeolites, silica gel and activated alumina. By worldwide sales, activated carbon is by far the most widely used — its manufacture and sale date back to the 19th century, and global annual demand for activated carbon exceeds 1.2 million metric tons. The most common raw materials for manufacturing activated carbon are coal, coconut shells, wood, peat and petroleum coke.

Adsorption

As with other sorbent materials, activated carbon works when molecules adhere to its surface in an adsorption process. Adsorption can be thought of as the accumulation of gaseous components, or solutes dissolved in liquids, onto a solid surface. Adsorption is primarily a physical process (substances do not undergo chemical reactions with the adsorbent). If chemical agents are applied to an adsorbent, they may react with solutes in a process known as chemisorption, in which the deposited substances are chemically altered.

Van der Waals (dipole-dipole) and London dispersion (induced dipole-induced dipole) intermolecular forces are important in the adsorption phenomenon, which can be rather complex in practice.

A host of factors influence the fine details associated with adsorption of molecules in a sample of gas or liquid onto activated carbon. Among these factors are the following:

- Molecular size of the substances to be removed from the bulk material
- Hydrophilic behavior of the substances to be removed
- Polarity of the substance to be removed
- Size of interior surface area of the adsorbent material
- Pore structure of the activated carbon material (shape, size distribution)
- Solute concentration
- Temperature and pressure
- Composition of the solution or gas mixture exposed to the adsorbent
- pH value of the solution (for liquid-phase)
- Relative humidity

Pore size and surface area

In the context of activated-carbon sorbent material, the term "activation" refers to a carefully controlled oxidation of carbon atoms in the raw material that greatly expands the material's internal surface area. The activation process forms a network of pores that extend from the ones that naturally occur in the carbonaceous raw material (Figure 1).

Activation results in a distribution of pore sizes and shapes that depend on the nature of the starting material and on the details of the manufacturing process. Macroscale pores are greater than 50 nm in size, while mesoscale pores range from 2–50 nm and microscale pores less than 2 nm wide.

The interior surface of activated carbon is measured and evaluated using the BET (Brunauer-Emmert-Teller) method. Activated carbons employed in gas and air treatment ordinarily have a BET surface area within the range of 800–1,500 m^2/g. Activated carbons used in water purification generally have BET surface areas of between 500 and 1,500 m^2/g. In adsorption, both interior surface and pore radius distribution play an important role.

Activation processes

Activated carbon manufacture can be accomplished by either gas activation or chemical activation.

Gas activation. Gas activation involves carbonization of the raw material at 400–500°C to eliminate most of the volatile matter, followed by partial gasification at 800–1,000°C. As the carbon material is partially gasified (via the chemical reactions shown below), a highly porous carbon skeleton is formed and large internal surface area results. A mild oxidizing gas, such as steam mixed with CO_2, is used because the intrinsic surface reaction rate is slower than the pore diffusion rate. This ensures that pores will develop uniformly throughout the material.

$$C + H_20 \rightarrow 2CO + H_2$$
$$C + 2H_20 \rightarrow CO_2 + 2H_2$$

Chemical activation. In chemical activation, non-incinerated carbonaceous material is treated with dehydrating or oxidizing chemicals and heated to between 400 and 800°C. The activating agents (usually zinc chloride, phosphoric acid, potassium sulfide or others) are leached out and recovered. Chemical activation is often used on lignin-based starting materials.

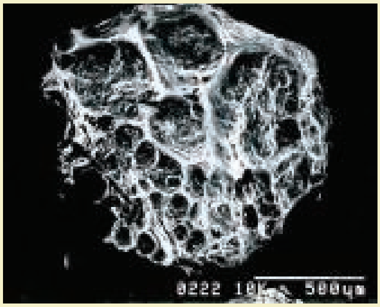


FIGURE 1. This micrograph shows a particle of activated carbon, with pores of varying sizes and shapes

The activation process is carried out in rotary kilns, multiple hearth furnaces, shaft or fluidized-bed furnaces, or in fluidized-bed reactors.

Applications

The most common product forms of activated carbon include the following types: extruded (usually in the form on cylindrical pellets), granular activated carbon and powder activated carbon (in specified particle sizes).

Activated carbon finds extensive use as an adsorbent for the removal of a wide range of contaminants from liquids and gases. It is also used to adsorb a product, such as a solvent, from a process stream, with the adsorbed product being subsequently desorbed onsite for reuse. The use of activated carbon in liquid-phase applications greatly exceeds its use in gas-phase applications. The three largest liquid-phase applications are treatment of potable water (37% of total activated carbon used), treatment of wastewater (21%), and decolorization of sugar (10%). The three largest gas-phase applications are air purification (40%), automotive emissions control (21%), and solvent vapor recovery (12%).

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Technology Profile

Extracting 1,3-Butadiene from a C4 Stream

By Intratec Solutions

The organic compound 1,3-butadiene is a petrochemical commodity used as a raw material for the production of rubbers and plastics, such as polybutadiene rubber (PR), styrene butadiene rubber (SBR), and acrylonitrile butadiene styrene (ABS). These materials are mainly applied in the manufacture of automotive parts, tires and cables. Also, 1,3-butadiene is used as an intermediate in the manufacture of several chemicals, such as adiponitrile, the raw material for nylon production.

1,3-Butadiene is generally recovered from C4 streams that are generated as byproducts of ethylene manufacture by naphtha-based steam cracking. These C4 mixtures are composed mostly of butadiene and butenes, with smaller amounts of butanes and acetylenes. To obtain the 1,3-butadiene product stream, it must be extracted from the C4 mixture. This can be accomplished using several technologies, such as separation by solvent extraction.

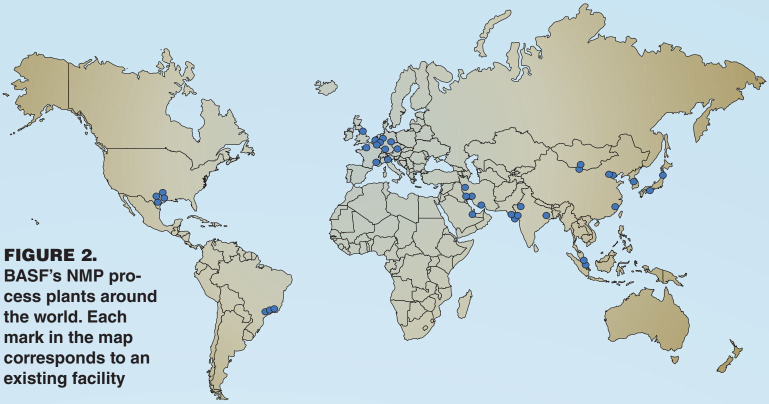

FIGURE 2. BASF's NMP process plants around the world. Each mark in the map corresponds to an existing facility

The process

The process depicted in Figure 1 is similar to BASF's (Ludwigshafen, Germany; www.basf.com) process for butadiene extraction using aqueous N-methylpyrrolidinone (NMP) as a solvent.

Extractive distillation. The C4 mixture containing butadiene, butenes, butanes and acetylenes is fed to the first extractive column, where recycled NMP solvent is added to the top section. The column overhead stream, which consists of butanes and butenes (raffinate-1), is sent to storage. The bottom stream, containing butadiene, acetylenes and some butenes absorbed in NMP, is fed to the top of the rectifier column. In this column, remaining butenes are separated in the top stream and recycled to the first extractive column, while the bottoms stream, containing mainly NMP, is sent to the degassing section. Butadiene and some acetylenes are separated as a side stream of the rectifier column, which is fed to the second extractive column. There, recycled NMP solvent is added to the top to absorb the acetylenes, which are recovered in the bottoms and returned to the rectifier column. Crude butadiene is recovered in the overheads and sent to the butadiene-purification section.

Butadiene purification. In this section, the crude butadiene stream is fed to the propyne column, where propyne is separated in the overheads. The bottoms stream of this column is sent to the butadiene distillation column, where 1,3-butadiene product is obtained in the overhead stream and heavy ends are separated in the bottoms.

Degassing. The NMP solvent from the bottoms of the rectifier column is stripped from the heavy hydrocarbons, which are separated as the distillate stream of the degassing column. These heavy hydrocarbons are then sent to a cooling column, where they are cooled by direct contact with NMP solvent and fed to the rectifier column through a gas compressor. In the degassing column, the acetylenes are separated as a side stream and washed in a scrubber before being purged. The NMP recovered in the bottom stream is recycled to the extractive distillation columns.

Economic performance

An economic evaluation of the process was conducted, taking into consideration a unit processing a C4 stream to produce 100,000 ton/yr of 1,3-butadiene erected on the U.S. Gulf Coast (the process equipment is represented in the simplified flowsheet below). The estimated total fixed investment for the construction of this plant is about $50 million.

An important feature of the presented technology is its low susceptibility to impurities, rendering it adequate to process any C4 stream, regardless of the butadiene content. Also, plants using this technology have been shown to operate continuously for more than four years.

In addition, the BASF NMP process technology is currently applied in several plants worldwide, as shown in Figure 2. ■

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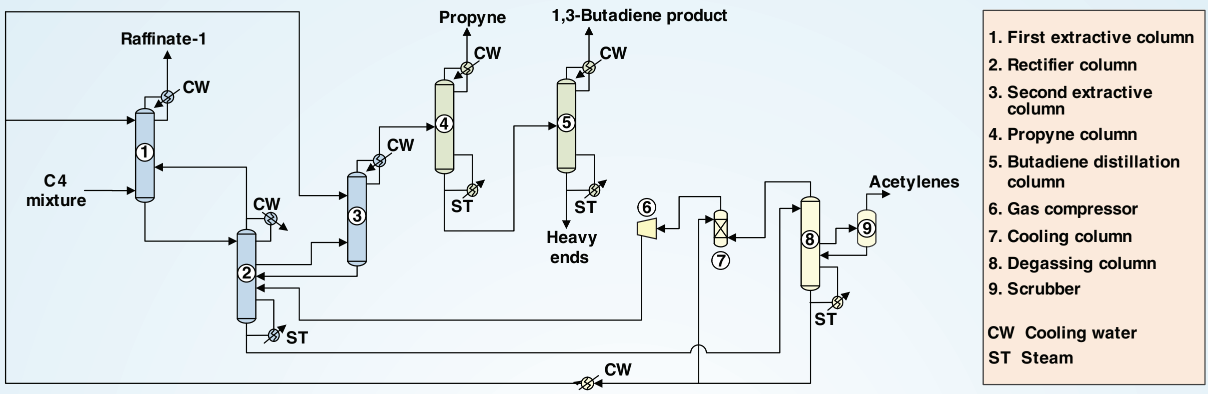

FIGURE 1. This 1,3-butadiene extraction process is similar to BASF's NMP process

Advanced Control Methods for Combustion

Advanced control techniques can raise efficiency and lower pollutant emissions in industrial combustion. The capabilities and adoption of several methods are discussed

Pal Szentennai
Budapest University of Technology and Economics
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Vienna University of Technology

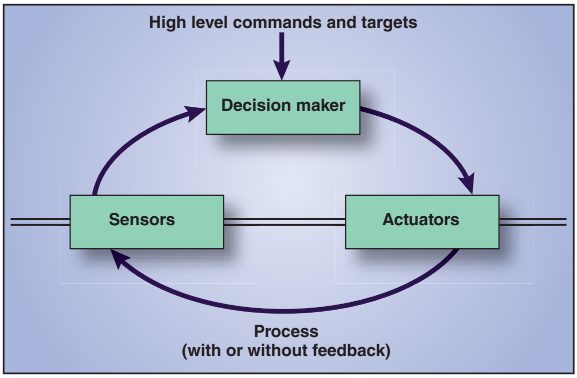

FIGURE 1. The concept and components of closed-loop control are shown here

Fuel combustion in engines, power plants, boilers, furnaces and other equipment provides energy for transportation, heating, electricity and goods manufacturing. Optimizing efficiency while lowering pollutant emissions is the main goal of industrial combustion, and reaching those goals, coupled with climate-change issues, have triggered a great deal of research in this field. One approach to improving the efficiency and emissions performance of a combustor is to apply advanced control techniques for both new and existing installations. This article presents several methods of advanced control for combustion, ranging from new diagnostic techniques to enhanced control schemes. Key benefits are cost savings through higher efficiency, environmental benefits through lower levels of pollutants, and increased safety.

Classic versus advanced control

Combustion proccesses account for 85% of global primary energy production [*1–2*], from electricity and heat generation to propulsion in terrestrial, marine and aerial transportation. Measures to increase efficiency encompass the combustion process itself, as well as fuel transportation and storage, and the use of its outcome (for instance, in cogeneration, waste heat is being utilized). Concerning pollutants, measures to limit or reduce their impact can be taken pre-combustion, during combustion and post-combustion. Prominent examples of these strategies include sulfur-free diesel fuel, air or fuel staging and selective catalytic reduction (SCR) of NOx.

Energy-efficiency and emissions strategies depend on the ability to control combustion processes. Classic combustion controls are based on temperature (for example, adjustment of the air-to-fuel ratio by peak exhaust gas temperature), flame emissions (such as the detection of misfiring in stationary engines by ultraviolet light detection), measurement of in-cylinder pressure in engines and measurement of CO, CO_2 or O_2 in the exhaust gases.

Advanced combustion-control strategies generally represent extensions and improvements to classical control methods. An advanced control system has a closed feedback loop (open-loop control systems do not have feedback). In combustion control, a sensor delivers data to a decision maker, which sends a signal to an actuator for reaction (Figure 1). Closed-loop control can steer a process better than one using an open-loop system [*3–4*]. This article focuses on advanced sensors and decision-maker algorithms, because these control-system elements have seen explosive development in the past two decades, whereas valves and actuators have changed comparatively little over that time. For more information on the fundamentals of process control, see Refs. *5–6*.

Advanced combustion control can be applied to virtually all types of combustors, including the following: gas turbines, furnaces, boilers and reciprocating internal-combustion engines, to name a few. Often, it is possible to retrofit existing installations so that significant economic and environmental benefits can be achieved [7].

Modern combustion options

Based on the huge variety of combustion applications, modern combustion processes differ significantly from each other. Distinctions can be made among combustion processes of gaseous, liquid and solid fuels. The two major modes of combustion are those with the fuel

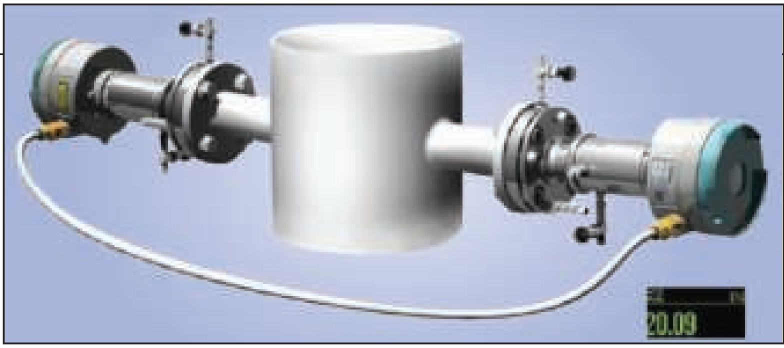

FIGURE 2. Oxygen concentration can be measured by tunable diode-laser absorption spectroscopy [*10*]

and oxidizer premixed and those where they are not premixed. There are also differences between laminar and turbulent combustion. For technical applications, turbulent combustion dominates, because it speeds up the process. However, non-premixed combustion is sometimes preferred for safety reasons. The following combustion processes can be termed "advanced":

- Lean combustion (to achieve low-NOx emissions)
- Carbon capture and storage (sequestration of CO_2 from combustion)
- Chemical looping combustion
- Oxyfuel combustion
- Co-combustion of fossil fuels with biomass
- Combustion of alternative fossil fuels, such as methane hydrate
- HCCI (homogeneous charge compression ignition) [*8*]

Advanced combustion is also discussed in Refs. *2* and *9*.

Advanced sensors

Combustion processes are difficult to probe, since high temperatures are involved. Often, conditions are transient, high pressures are present and multiple interferences, such as soot particles and background radiation, disturb measurements. Parameters to be measured include temperature, pressure and species concentrations. Generally, one can distinguish in-situ measurements (which probe the combustion processes directly "at the spot") and ex-situ measurements, which draw a sample that is analyzed in a controlled manner outside of the process (for example, in a gas chromatography instrument). The criteria for selecting suitable measurement methods are time resolution, sensitivity, type of measurement (such as point-measurement or two-dimensional, spatially resolved or integrated signal) and cost.

Optical, and particularly laser-based methods, lend themselves to in-situ measurements. A major advantage of optical techniques is that they do not perturb the probed system, hence avoiding measurement errors from sampling. Light can interact with matter in three basic modes: absorption, emission and scattering.

Advanced light-absorption sensors. The technique of tunable diode-laser absorption spectroscopy (TDLS) can measure species concentrations and temperatures of simple gases, such as CO, CO_2, O_2, NH_3 and CH_4, quantitatively by selective light absorption in the infrared spectral region by the target molecules. By tuning the laser wavelength around the respective absorption feature, users can compensate for non-specific effects, such as beam steering, background radiation and partial beam blockage by soot particles. A typical setup in the stack of a combustion process is depicted in Figure 2. It consists of a transmitter and a receiver unit.

In an exhaust stack, this type of sensor can measure NH_3, for example, so it can minimize the use of urea supplied to the NOx removal unit further upstream. Other examples are given for a municipal waste incineration plant (Figure 3). In this example, oxygen and temperature are measured in the combustion chamber. The measurement range for O_2 is 0–15% (accuracy ±0.2%), and that for the temperature 750–1,100 °C (accuracy ±30°C). The response time is 1–3 s. The signal can be used to control the feed of fresh air. This is important because the composition of the fuel varies a great deal and the measurement can help achieve optimal combustion.

On the exhaust side, emissions control based on TDLS measures NH_3 and HCl to control fluegas treatment for optimum cost and lowest emissions. Cost savings can be achieved by avoiding excessive chemicals dosing and lowering corrosion. TDLS has become a mature technology in advanced combustion control. A related approach, infrared absorption tomography for active combustion control, is described in Ref. 12.

Advanced sensors based on light emission. A technique based on light emission that combustion researchers frequently use is laser-induced fluorescence spectroscopy (LIF). It can be deployed to obtain two-dimensional images (planar-LIF, P-LIF) of species concentrations, including radical species such as ·OH. However, the setup is complex, so this technique has not yet found industrial use for combustion-control purposes. The test of a closed-loop equivalence ratio control of premixed combustors using a chemiluminescence signal is described in Ref. 13.

Advanced sensors based on light scattering. Laboratory-based methods that rely on scattering are Raman scattering and Cars (coherent anti-Stokes Raman scattering) spectroscopy. Like LIF, due to their complex experimental setup and difficult data evaluation and interpretation, they are not yet used for industrial combustion control applications.

Advanced sensors based on other signals. In Ref. *14*, an advanced closed loop combustion sensor based on ionization is described. Ref. *15* uses pressure signals, and Ref. *16* image-based controls for a closed-loop setup. A review of sensors for combustion control is provided elsewhere [*17*].

Advanced decision makers

The term "decision maker" refers to the computer hardware and software necessary to run the control algorithms that govern the adjustment of the combustion system parameters. The hardware basis of the central, decision-making part of advanced combustion-control systems will always be chosen in accordance with the expectations of the specific application. These expectations can vary widely among applications, even in cases where the combustion itself is basically similar. Gas turbines are applied, for example, in both stationary power plants and in jet aircraft engines. The expectations of the former case allow rack-mounted hardware elements in an extra chamber, while special microcomputers ("embedded systems") of minimal sizes and weights are required in the aviation industry. Rack-mounted hardware and embedded systems can be considered as the two ends of the spectrum of the hardware that is generally used for decision makers of combustion control, and selecting among them will be mostly determined by the application area, rather than by the combustion process itself.

Although the hardware platforms of the control decision-maker can be very different, a common requirement is superior reliability. The same is also true for the software side of the decision makers. In order to satisfy the need for high reliability with an acceptable cost, supplier companies deploy many modern tools of quality control and standardization on several levels.

Another consequence of the need for high reliability may be some degree of conservatism with regard to new ideas for improving reliability. This phenomenon can be observed in many other similar situations in which reliable operation is an absolute priority. Several industry branches, including oil-and-gas, chemicals and food, are characterized by the presence of high pressures and temperatures, and the involvement of hazardous materials and expensive assets and raw materials. This necessitates a high level of security. Although for industrial combustion control this conservatism may be somewhat exaggerated, numerous statistical analyses [*18–20*] do suggest a definite lag in the use of advanced control technologies for combustion processes instead of traditional ones, compared to the use of advanced controllers in other types of industrial processes (see box, p. 37).

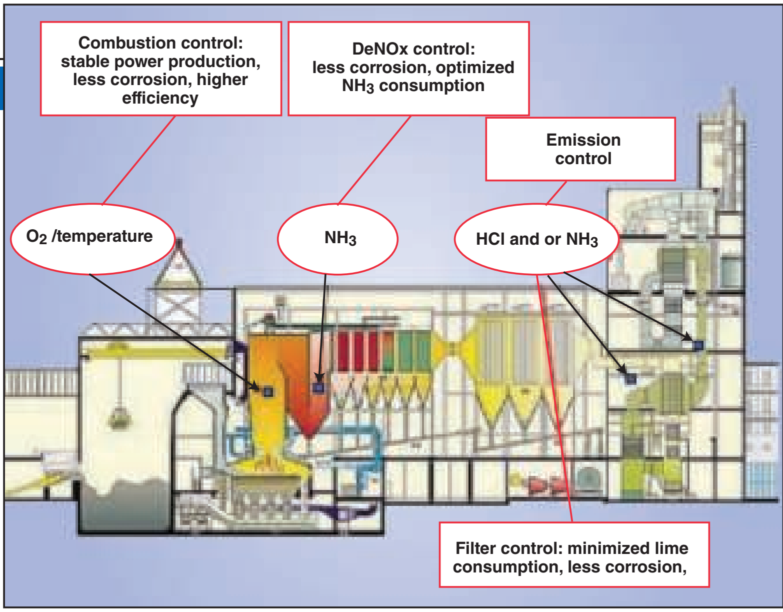

FIGURE 3. TDLS measurements are used in a municipal waste incinerator. The dust load is 5–10 g per standard cubic meter, the path length of the measurement is 3–8 m. Fast measurements with large temperature variations pose the main challenge [*11*]

Built-in software tools realizing some advanced control algorithms as part of decision makers will be provided by most suppliers of industrial control systems. Although very often, ranges and functionalities of these tools are still rather limited. In these cases, an option for realizing them is an external, general purpose (maybe PC-based) computer, where the need for clear interfaces between traditional and advanced control systems will be set up and realized. This approach can be followed not only in the case of new control systems for combustions systems, but also while upgrading existing plants.

All advanced methods offered by the control theory to be realized as software elements of decision makers cannot be discussed here, of course. The literature is voluminous, but some textbooks are available [*25–29*]. Some existing directions and results of modern control theory may have crucial significance in other application areas like robotics and flight stabilization [*30–32*]. However, a brief overview is included here of those methods that (1) are mature enough, and (2) show significant potential for use in industrial combustion control applications. Most of them are model-based procedures, a fact that revalues all activities on modeling combustion systems. Both theoretical and empirical modeling directions have their roles and importance, and a rapid increase of semi-empirical modeling can be observed nowadays [*33*].

Model predictive control. Almost all distributed control system (DCS) vendors offer model predictive control (MPC) as an advanced extension to their standard control algorithms [*15*], and this appears to be the most frequently used advanced control method currently. The reasons for its relatively wide use come from its relative simplicity and from its inherent properties that fit well with the general requirements of industrial combustion control.

The history of MPC has resulted in several variants, the most important of which is DMC (digital matrix control). It can be considered as a subset to MPC, characterized by simpler algorithms requiring less online computational demand, and the lack of some services of MPC, like handling constraints inherently.

This is actually one of the most important advantages of MPC in many real industrial applications. While theoretical control may disregard constraints, real applications definitely cannot. Examples in combustion processes are actuators (for instance, fuel-supply valves), which are evidently characterized by their limited operating ranges. Further-

ADOPTION OF ADVANCED CONTROL TECHNOLOGIES

Advanced control techniques offer opportunities for effectively handling combustion systems that have strong nonlinearities or internal couplings, and that therefore cannot be satisfactorily handled by the commonly applied traditional PID (proportional, integral derivative) controller, which is characterized by linear and scalar behaviors. Published data are available on the shares of advanced control methods for several years up to 2008, which clearly show that the application of advanced control methods for power plants and industry boilers are far below those in the chemical, oil-and-gas and petroleum refining industries, for example. In 2008, the power industry spent the most on DCS (distributed control system) upgrades and replacements, while it spent the least on advanced process control (see Table 1 in Ref. *18*).

What reasons could explain these data? Instead of exact answers, some differences will be identified and discussed here. It may be that combustion processes do not dictate so definitely the applications of advanced controllers, because some other chemical processes are characterized by much stronger nonlinearities. But in reality, combustion processes are also nonlinear, especially when considering their entire load ranges. It is true that these nonlinearities are less significant, and they predominantly can still be kept in operation by means of traditional linear tools. However, industrial practice shows clearly that this approach leads to efficiency reductions already in the simplest case of a power plant boiler running below its base load.

TABLE 1. RATIOS OF WORLDWIDE SALES OF APC RELATIVE TO WORLDWIDE SALES OF DCS*

Industry	Refining	Oil and gas	Chemical	Power
Ratio of APC sales over DCS sales	0.092	0.061	0.050	0.010

* Ratios of worldwide sales of APC (advanced process control) relative to worldwide sales of DCS (distributed control systems) in several industries in 2008. Adapted from Ref. *18*.

In some cases of combustion technologies, the suboptimal efficiency associated with traditional control methods is no longer acceptable, or the traditional control methods simply do not work. In these cases, the application of advanced controllers is dictated already. Many such examples were reported together with success stories of solving them [*21–24*]. They include a wide range of combustion processes, from compensating for unacceptable fluctuations of biomass boilers with soft sensors, to lambda control of internal combustion engines by means of a robust predictive controller.

A further question is, of course, what factors block the dissemination of advanced control methods in those cases in which an obvious limitation of traditional control may not necessarily be present, but where advanced control methods would assure significant increases in efficiency and flexibility, or decreases in lifetime consumptions of critical parts.

For collecting the answers to this question, and for formulating some advice on overcoming most blocking factors, a workshop took place in May 2012 at the Budapest University of Technology and Economics. A group of experts in three categories — plant operators, equipment suppliers and researchers — came together from four countries to discuss the issue in an unstructured, interactive format. From the workshop, a number of basic statements emerged. They are summarized here.

An important reason for the low level of advanced control methods in combustion processes in the energy industry is the presence of gaps between several actors. A lack of communication exists among people and institutions working on the same topic. Key people involved working on industrial combustion projects in the areas of control, energy, management and financials are often unable to balance benefits and drawbacks from the perspective of each of their separate fields. Several platforms for bringing people together could help the situation, as could the use of a common language. This common language could be money. However, expressing certain benefits (such as safety, usability and lifetime reduction) in the context of money is not straightforward. Education could also help in connecting control theory with system theory, university with industry, and practice with theory.

Safety is another issue that slows down the utilization of advanced control in combustion processes. Safety is the highest priority, however, it can be warranted not only by traditional controllers but also by means of a proper structure in the control system. Traditional controllers should be used on a higher, supervising level, and very clear interfaces should be built with the advanced control elements [*21*]. Consider that this approach will also assure further benefits. Additional certification costs for safety-related control elements can be avoided, as can some of the risk arising from frequent version changes of the hardware and software platforms running the advanced control computation methods.

Software elements of advanced decision makers must follow the same safety-related requirements as their hardware components, as discussed above. That's why, also the above discussed considerations in applying them should be followed in this case — especially regarding the structure and clear interfaces joining traditional and advanced elements. The same idea also suggests that the range of control tasks to be realized on the basis of advanced methods must be selected carefully. Positioners of actuators are, for example, advised to be kept unchanged for simplicity and reliability. Also, simple tasks of low significance should not be involved in the area of tasks to be realized by advanced control methods. ❑

more, MPC is also able to consider other constraints without direct relationships to the process in question. If the control system is well designed, this ability can be perfectly utilized for limiting temperature stresses in key structural elements of a combustion system during load shifts, for example.

Another advantage of MPC against the traditional PID is that is it multidimensional. As a result, internal cross-couplings of the combustion process can be handled inherently. There is no need for figuring out the significance of the cross-couplings. An example is the cross-couplings between load control and lambda control in a boiler.

The basic MPC algorithm itself is a discrete time on-line optimization, which requires a dynamic process model. The more accurate the model, the better the control performance that can be expected. However, model inaccuracies will be effectively compensated by the controller. Prior to the controller design, the constraints must be given, along with two further parameters, the so-called weight matrices. They form a very clear representation of the design criteria for balancing between two contradictory requirements of all control tasks — accuracy and quiet actuator movements.

Intelligent control methods. With respect to control methods, the term "intelligent" suggests those with origins in artificial intelligence research. Two basic control methods fall into this category: artificial neural networks and fuzzy control. Both are excellent tools for controller design in cases where the formulation of control-system rules on the basis of traditional mathematical formalism is very difficult.

In many situations, the control rule is available by verbal statements only, which arise from human thinking. This set of control rules can be called "expert knowledge," and a very effective way of representing

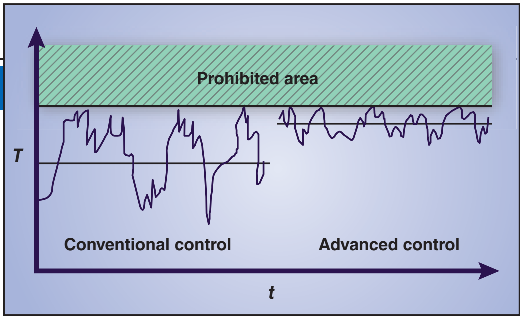

FIGURE 4. Conventional control (left) and advanced control (right) of a power plant. The latter allows a higher average boiler operating temperature, which translates into efficiency gains [*21*]

it is a new direction of mathematical set theory called "fuzzy logic." Artificial neural networks are very effective when the learning capabilities and methods of the human brain need to be applied on the basis of corresponding input and output data sets of a system. Although several similarities exist between these two intelligent control methods, and their combined application is a popular solution, they will be discussed further separately.

The central element of a fuzzy controller is a "rule base," containing rules formulated on an "*if* ... *then* ..." logic scheme. (Example: "*if* the mixture temperature is very high, *then* set coolant valve to totally open.") The previous fuzzy control element is called "fuzzification," while the following one is "defuzzification." In the prior one, analog quantities (such as temperature) will be fuzzified; that is, ordered into the discrete groups (sets) that correspond to "intermediate," "high," and "very high." An important point is that the borders of these groups (or sets) are not crisp, like they would be in classical set theory. This grouping is much closer to human thinking, which generally does not draw a crisp borderline between the sets distinguishing the age of a person to sets like "youth" or "middle-aged," for example. Defuzzification is a procedure in the opposite direction.

The characteristics of a fuzzy controller make it effective for controller design. The simple realizability of each element of the fuzzy controller is another advantage. This simplicity of operation allows the possibility of using it in low-cost applications. Limitations of fuzzy controllers arise from the basic principle, which may result in unsmooth outputs. Clear stability criteria for those are still lacking.

The basic concept behind artificial neural networks (ANN) was inspired by the human nervous system, the basic element of which is the neuron. Like its biological counterpart, an artificial neuron is a multi-input, single-output element, which is organized into networks that give rise to multi-input, multi-output (MIMO) systems. The strengths between the neuron interconnections can be varied, which establishes the basis for the ability

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to learn. Special optimum-seeking algorithms are used during the learning phase to find these interconnecting strengths (weightings), so that the network outputs that result from training inputs would best fit the target outputs that correspond to the same inputs. If the output of a combustion process will be applied as training input to the ANN, and the process input is applied as a target output of the ANN, the artificial neural network will be trained as a controller. After the training phase, the ANN will be able to find the process input to match the desired process output.

General experience with artificial neural networks suggests that they have excellent capability for learning the corresponding input–output pairs. However, in the case of inputs that lie somewhat further from the training-input data, error margins from the ANN output may be surprisingly large.

Advanced controller tuning. A possible upgrade of traditional controllers, such as PID controllers, is the application of advanced methods for optimizing their parameters, or possibly changing their configurations. Most of the configurations on this basis belong to a wider theoretical approach called "adaptive control." Most important for combustion control are "gain scheduling" and "multimode control." Both concepts require a "scheduling variable," the actual value of which essentially characterizes the process behavior. In the case of combustion processes, a very good candidate for this is the load signal. However, the introduction of further variables may result in two- or multi-dimensional scheduling variables as well.

In the most frequently applied case, the one-dimensional scheduling variable will be divided into discrete ranges, within which one set of tuning parameters or controller configurations will be applied. If the parameter set of a controller will only be changed while shifting from one section to another one along the scheduling variable range, the system is called "gain scheduling," while in other cases, the entire controller will be changed. The latter case is called "multimode control," which has greater adaptivity but also higher complexity.

The relative simplicity of these techniques is a great advantage, although assuring bumpless changes between the operating ranges requires significant designer effort and knowledge.

Loop decoupling. Similar to the previous controller tuning, loop decoupling is not really an advanced control method, but rather an advanced extension to classical control methods. This technology can be applied to processes characterized by strong internal cross-couplings. That is, for processes in which the independent, scalar control loops strongly disturb each other. Based on a process model, a so-called decoupler can be designed. A decoupler is a dynamic system in the DCS, and its outputs will be directed to the inputs of the actual process. The aim of this design is that the virtual system that results from the decoupler plus the process itself form a system free of internal cross-couplings. And this type of system can already be controlled by a series of classical controllers. The limitations of this method are evident, however. If linear controllers (like classical PIDs) are intended to be used for the virtual system, and the actual process is not linear, then the method can get rather complicated.

Benefits of advanced control

The advantages of advanced combustion control are mainly higher efficiency and lower pollutant levels, although other goals such as higher safety levels are possible. Advanced control can be characterized by fast response times, and allowing a process to be run within a narrower window of process parameters (Figure 4).

When the deviations around the setpoint are smaller, it is possible, as the example shows, to increase the average operation temperature of the combustor (in this case a boiler), and still avoid overheating the furnace. By raising the operating temperature, the overall thermal efficiency can be augmented.

The example discussed earlier illustrates a special characteristic of the advanced combustion control. Namely, that two goals can be served simultaneously — in conventional cases, these are in opposition to each other. For example, the introduction of carbon capture facilities will significantly increase fuel consumption, and by extension, operating costs, while an efficiency boost will decrease both emissions and fuel cost. And this end can be achieved through the use of advanced combustion control, the investment costs of which are far lower than those of any other modifications in the process itself.

It is likely that several advanced combustion-diagnostic methods currently used exclusively in laboratories will eventually find their way into industrial applications to further optimize combustor performance in various applications. And existing combustors stand to benefit as well, beause they can often be upgraded with advanced combustion control technology [7]. ■

Edited by Scott Jenkins

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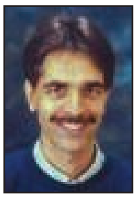

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New Horizons For Dividing Wall Columns

How to significantly expand the application window of DWCs, both as a new design to enhance potential benefits and as an energy saving retrofit option

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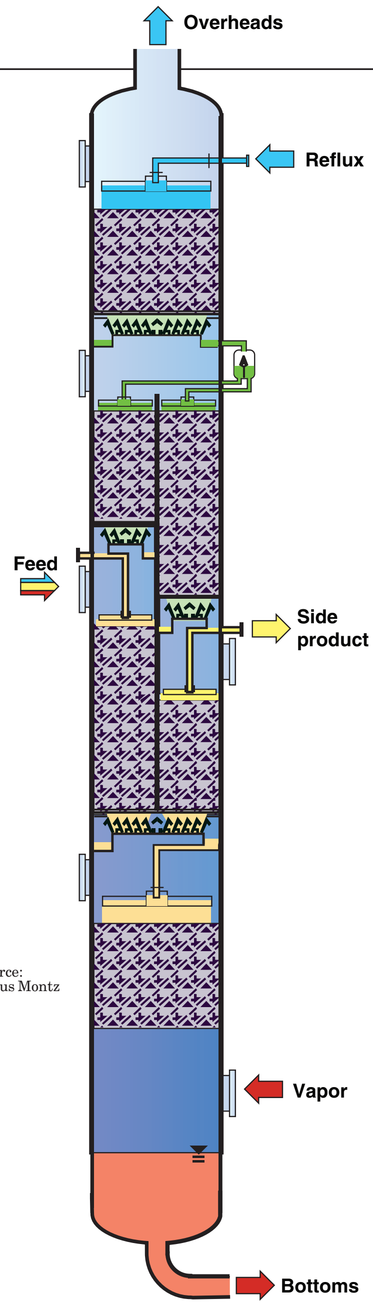


FIGURE 1. Shown here is a side view of a simple dividing-wall column (DWC) that is equipped with structured packing

A dividing wall column (DWC) is an atypical distillation column with an internal, vertical partition wall that effectively accommodates — within one shell — two conventional distillation columns that are connected in series as required when separating a multicomponent feed mixture into three pure products.

DWC components

Figures 1 and 2 show the anatomy and main components of a conventional packed DWC, with a centrally placed partition wall separating the prefractionator column (feed side) from the main column (product draw-off side), each of which contain just one bed above and below for simplicity. The prefractionator with a rectification section above and stripping section below the feed resembles the configuration of a typical column.

On the main column side, there are two binary separation sections placed above each other. Therefore, the section above the side-product draw-off is the stripping section of the upper column, while the section below the side-product draw-off is the rectification section of the lower column. If a conventional column with an external side-rectifier is replaced by a DWC, then the partition wall will extend from around the middle to the top of the shell, or, in case of a column with an external side-stripper, to the bottom of the shell [*1–3*].

As shown in Figure 1, the reflux is distributed over a conventional bed in the top and upon leaving this bed it is collected and split, according to requirements, into two streams delivered to the distributors on the prefractionator and main column sides of the partition wall, respectively. This is done using a proprietary device shown in Figure 2a, which was originally designed to serve as a reflux/distillate splitter. Liquid leaving each of two packed beds in the partitioned part of the column is collected, mixed and guided to the distributor of the lower bed. Here and in all other liquid redistribution sections, common chevron- and chimney-type liquid collectors are used for this purpose in conjunction with a narrow-trough distributor, all adapted to fit into the given cross-sectional area. On the prefractionator side, this is the place where the feed stream is added, and on the main column side it is where the side product is taken out of the column.

Figure 2b shows a photograph of an installed narrow-trough distributor with predistributor box and a downpipe coming from the collec-

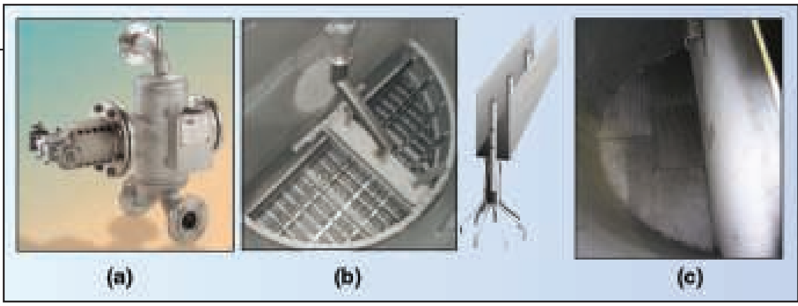


FIGURE 2. These photographs show (a) a reflux splitter, (b) an installed semi-circular narrow trough liquid distributor, and (c) the layout of the top layer of structured packing installed in a partitioned section of the column

tor above. The insert beside Figure 2b shows a drawing of a narrow trough with drip tubes containing drip point increasing legs (Montz type S). Such distributors are used for very low specific liquid loads (<1 m^3/m^2h) as encountered in deep vacuum applications, and have been found to perform well.

One should note that in a DWC there are at least six sections, which may differ considerably in liquid or vapor (or both) loads. A ring welded to the column wall is used to position and fix the distributor, and an inspection manway is placed in the partition wall. The liquid leaving the lower beds from the prefractionator and main column sides is collected, mixed and delivered to the bed in the conventional bottom section of the column.

Figure 2c shows the top view of a semicircular packing layer consisting of tightly packed segments. Depending on the nature and operating conditions of separation, both gauze and sheet-metal packings are used. The former, usually with a specific geometric area of 500 or even 750 m^2/m^3, are preferred in demanding separations under deep vacuum, while the common choice for moderate vacuum and near atmospheric applications are corrugated-sheet-metal structured packings with surface areas of 200 to 350 m^2/m^3, in both conventional and high-performance versions.

Regarding design and operation, a distinguishing feature of a DWC is the so-called "vapor split," that is, the distribution of vapor ascending from the conventional bottom part of the bed into two streams, one entering the prefractionator and another entering the main column side. This occurs spontaneously, and the resulting vapor flowrates correspond to those required to arrive at the same pressure drop on both sides of the partition wall. A prerequisite for good functioning of a DWC is that the vapor split arranged by hydraulic design in conjunction with fixed liquid flowrates provides vapor flowrates that will comply with the liquid-to-vapor ratios required to accomplish the desired separation at the prefractionator and main column sides.

Proven advantages

As proven in many industrial applications, a three-product DWC enables, on average, 30% saving in energy and an equivalent saving in capital, as well as a considerable reduction of required plot area compared to conventional two column sequences [*4–6*]. Other potential benefits include reduced thermal degradation of sensitive products, often increased product quality and recovery in case of specialty chemicals, reduced number of equipment to control and maintain, and more. Knowing all of the potential benefits, it is strange to see that nearly thirty years since the first industrial application of a DWC (see box, right), the number of installations is still relatively quite small — approximately 200, which is practically negligible compared to the number of distillation columns in operation worldwide.

The applications described in the box, and many others — even with highest, electronics-grade purity requirements — have proven that a DWC, although atypical, is just a distillation column, arranged in a more compact and direct way than is the case with two- or three-column sequences used throughout the process industries to obtain three products of desired purity.

Full thermal coupling, as employed in a DWC, will always ensure an energy saving that is approximately equivalent to the energy required by the smaller of two reboilers employed in the conventional sequence, provided the nature and conditions of the separation being considered will not make it unfeasible. Indeed, this may appear so in certain cases;

CHRONOLOGY OF DWC TECHNOLOGY

Figure 3 shows the number of DWCs delivered over the years by a German vendor. One can see in Figure 3 that the first two DWCs were delivered in 1985, and from 1996 the number of applications is growing faster steadily. The point of onset of a stronger increase in the number of deliveries coincides with the adoption and implementation of DWCs with non-welded partition walls. This can be considered as the first milestone in the development of this technology.

Indeed, by adopting non-welded wall technology, it became possible to place the partition in an off-center position, which allowed accommodation of separations with much bigger variations in composition and relative volatilities of components as well as two phase feeds than before [*7*]. Even more, it enabled cost-effective design and construction of the first DWC for obtaining four products in one shell [*8*]. Such a DWC configuration, known generally as "Kaibel column", was introduced in 1987 by G. Kaibel [*9*] and installed for the first time in a BASF SE plant in 2002 [*8*]. These were equipped with structured packings.

The first and very successful revamp of a conventional side-product pyrolysis gasoline fractionation column using structured packings was reported by Uhde (now ThyssenKrupp Industrial Solutions) in 2000 [*10, 11*]. A 7-min video showing this project can be found on YouTube, under "The Divided Wall Column". Another application success story from Uhde is the first DWC accommodating Morphylane extractive distillation process [*11*].

The first tray DWC was put into operation at a Sasol plant in South Africa in 2000 [*12*]. With this another milestone was reached, and the DWC made an inroad into petroleum refining world dominated by large scale applications. Interestingly, the second tray DWC installed at Sasol, with an internal diameter of 5.2 m and a tangent-to-tangent height of 100 m, is one of tallest distillation columns ever built. Other refiners followed soon, reporting successful revamps of typical side-product columns including in one case off-center position of a non-welded partition wall [*14*]. ❑

for instance, if a four-product DWC is considered in conjunction with the separation of a wide boiling feed.

Regarding the practitioners reluctance to consider design and implementation of four-product DWCs, there are certain process and mechanical design and operation-related concerns, which require a thorough consideration. By applying adequate solutions, a DWC could become a cost-effective alternative for conventional sequences, both as a new design or a retrofit option. What we aim at here is to address the potential for further expansion of the application window, and convince the readers that the implementation and versatility of a DWC is not as limited as generally believed (that is, as suggested in extensive literature, which contains mainly redundant information).

Julius Montz

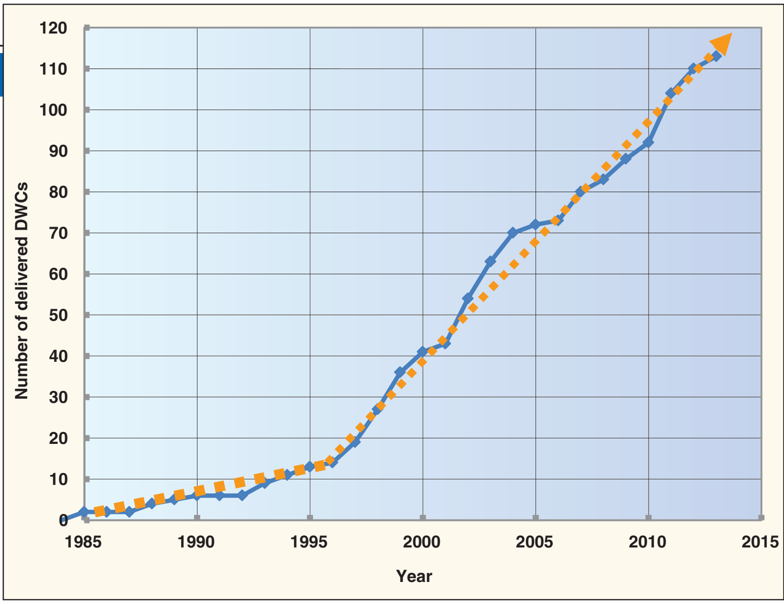


FIGURE 3. This graph shows the number of DWCs delivered by a German vendor over the years

New openings

Upon reading the most recent publication by Staak and others [*15*], which describes a highly successful application of a multi-purpose DWC in a Lonza chemicals processing plant in Visp, Switzerland, we may say that a technology breakthrough has occurred that will mark another milestone in the development of DWC technology. Among other periodic operations, this DWC has also taken over the function of a batch distillation column, enabling both higher yield and higher bottom product purity, thanks to a large reduction of bottoms temperature. The added benefits, as experienced in this case, are expected to be more than appealing to move others to look for similar applications.

The first four-product DWCs reflect the simple, single-partition wall configuration proposed by Kaibel in 1987 [*9*], which is shown schematically in Figure 4. As described elsewhere [*8*], this configuration appeared to be practical and within the range of existing know-how and experience, but, thermodynamically it is not optimal. In the space in between the two side-product draw-offs, a certain amount of remixing of the medium-boiling components occurs, resulting in entropy formation, that is, a less energy-efficient operation than is achievable with a configuration that employs full thermal coupling.

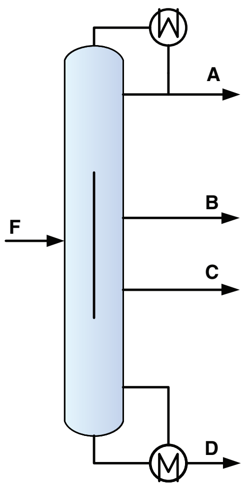


FIGURE 4. A single-partition wall, four-product DWC, also known as a Kaibel column, is shown here

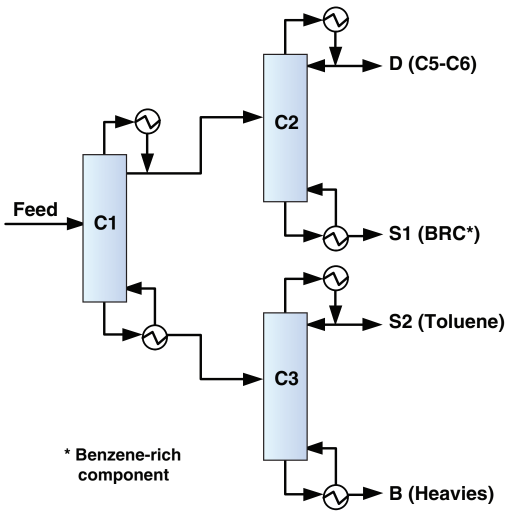


FIGURE 5. Shown here is a typical sequence of three simple-distillation columns for the separation of an aromatics mixture into four product streams, considered in the present study

A logical next step would be to consider implementation of more complex, fully thermally coupled DWC configurations for obtaining four products, to maximize potential energy, capital and plot area savings. However, the chemical process industries (CPI), particularly the large-scale sectors, like petroleum refining, gas processing, petrochemicals and chemicals manufacturing industries, although under heavy pressure to comply in the short term with legislation for the reduction of CO_2 emissions — which can effectively be reached by implementing DWC and other energy saving distillation technologies — seem to be reluctant to make a decisive step in that direction. The reason for this may be a lack of established design procedures and fear of unstable operation.

Realizing that this may be a major burden, we have recently undertaken, in a cooperative effort with I.J. Halvorsen of Sintef ICT

TABLE 1. BASE CASE FOR FIGURE 5					
	Feed (F)	C5-C6 (A)	BRC* (B)	Toluene (C)	Heavies (D)
Flowrate (ton/h)	31.7	7.4	3.9	8.0	12.4
Mass fractions					
n-Hexane & lighter	0.2517	0.9869	0.1642	-	-
Benzene	0.0855	0.0131	0.6750	-	-
3-Methylhexane	0.0204	-	0.1608	0.0026	-
Toluene	0.2474	-	-	0.9718	0.0061
Ethilbenzene & heavier	0.3950	-	-	0.0256	0.9939
*BRC = Benzene-rich component					

and S. Skogestad of the Norwegian University of Science and Technology (NTNU; Trondheim, Norway), a joint research effort to thoroughly evaluate the design and operation of various feasible configurations of a packed four-product DWC using an industrially relevant aromatics plant as a base case [*16–18*]. Figure 5 shows the base case configuration considered, and Table 1 contains a summary of feed and product compositions. The hydraulic design and packed-column dimensioning methods for three- and four-product DWCs used in these studies are described in detail elsewhere [*19, 20*].

According to detailed simulation studies summarized in Ref. 18, both energy and capital savings in excess of 50% appear to be achievable. Such a high potential for reduction of CO_2 emissions and increased competitiveness creates a strong incentive to consider implementation of four-product DWCs in practice.

Coupled four-product DWC

Minimization of energy requirements in the case of a four-product separation implies employing a Petlyuk or full thermal-coupling arrangement, which requires an internal configuration with three sections in parallel as shown in Figure 6a. Such a complex configuration with three liquid and three vapor splits has not yet been attempted in practice.

As mentioned before, for a given liquid split, vapor splits are set by the amount of flow resistance arranged during the design, and the flowrates leading to pressure-drop equalization should comply with those required by separation (a fixed L/V ratio for each of sections in parallel). These could be influenced to a certain extent by manipulation of liquid flowrates, but proper control would be possible only if provisions could be made to influence vapor flows during operation. Such devices are not yet available commercially and some indication on developments in that direction can be found in the patent literature.

Confronted with this, the previously mentioned research consortium has considered various options and arrived at a considerably simpler internal configuration, shown schematically in Figure 6b, which is equivalent to the fully thermally coupled one (Figure 6a), but includes only two vapor splits. Table 2 contains basic performance data as obtained for conventional and three four-product DWC configurations shown in Figures 4, 5 and 6. The energy and column-volume saving numbers speak for themselves, indicating that even a non-optimal, but proven single-partition DWC will bring impressive gains compared to the conventional sequence.

More competitive in this respect is a fully thermally coupled, multi-partition DWC, which requires 15.5% less energy and 16.5% less volume than a single-partition, four-product DWC. So in the present case, there is no doubt whether to go for a DWC, but the question is for which one. Although significant, the difference in related capital cost savings (for details, see Ref. 18) may appear to be the less important argument here than financial benefits for years to come based on total cooling and heat-input savings. These are more than appealing and should justify at least a serious consideration of design and practical implementation of a two-partition-wall DWC in this and similar situations.

Figure 7 shows a detailed drawing of this column, including auxiliary equipment, indicating that the zone above the feed containing three sections in parallel is rather short, with bottoms of three beds at the same level. The middle one is a narrow bed, which is taller than that on the prefractionator side and shorter than that on the main column side. Such a demanding configuration could be assembled as a packed column, using existing non-welded technology know-how and means utilized during construction of single-partition-wall, four-product DWCs [*7, 8*].

Figure 8a shows the top view of cross sectional areas at three characteristic elevations. In case of off-center positioning of the partition wall, these sections can be smaller and/or larger than a half-circle, while in the column segment with three sections in parallel the cross-sectional area of the middle bed is practically rectangular. Those feeling uncomfortable with this layout could consider, for this segment of the DWC, a concentric column arrangement (see Figure 8b) with the middle column bed placed in the inner column, and prefractionator and main column sections placed in the annular spaces of the outer ring. Both packings and trays can be made to fit into the given form, but special attention needs to be paid such that flow patterns of phases are arranged to resemble that associated with common practices. In the case of trayed DWCs, layout of the tray (that is, placing downcomers and arranging favorable flow paths) may become a serious challenge. In the case of packed DWCs, the partition walls introduce additional wall-zone area. To avoid potential performance-deteriorating wall effects, structured packings need to be equipped with effective wall wipers, and for trays, downcomers need to be placed in dead zones and so on. However, all this belongs to established distillation column know-how and design practices, and designers involved

TABLE 2. DIMENSIONS, INTERNALS, OPERATING PRESSURES AND PRESSURE DROPS OF CONVENTIONAL THREE-COLUMN SEQUENCE (C1/C2/C3), SINGLE-PARTITION, THREE-PARTITIONS AND TWO-PARTITIONS DWCS CONSIDERED IN THIS STUDY	C1/C2/C3	Single partition	Three partitions	Two partitions
Top pressure, bar	1.7/2.7/1.013	2.5	2.5	2.5
Reboiler duty, MW	3.8/3.1/3.1	5.7	4.81	4.81
Energy saving, %	—	43	52	52
Stage requirement, No.	40/38/38	169/129*	202/130*	174/130*
Sieve trays, No.	61/59/59	—	—	—
Shell height, m	40.5/39.5/39.5	68.6	69	69
Shell diameter, m	2/2/1.8	2.2	2	2
Packed beds	—	10	13	11
Shell(s) volume, m^3	352	261	216	216
Shell volume saving, %	—	26	39	39
Pressure drop, bar	0.31/0.27/0.24	0.114	0.117	0.105

*Main column stage count

with complex tray and structured packing arrangements should be able to arrive at best solutions in given situations.

A non-welded wall, where appropriate, enables easy and precise assembly of packed beds of various shapes separated by partition walls [7]. Namely, the installation progresses as in a conventional column, and the partition wall is also assembled progressively by adding new elements. These are in dimensions that are easy to handle and quite light, because the thickness of the non-welded partition wall can be as low as practical — usually 1.5–2 mm. Packing elements adjacent to the partition wall are equipped with robust wall wipers that, in addition to scrapping the liquid from the walls, also serve to fix the partition wall in place. This implies that installed beds can also be easily removed, if required in case of troubleshooting or a revamp.

An important advantage of a non-welded partition wall is avoidance of potential welding-related problems (thermal stresses, flatness of the wall), which may become pronounced when a partition wall needs to be welded in an off-center position. On the process side, the main concern is the possibility of product(s) contamination, by allowing small amounts of vapor or liquid (or both) on the wrong side of the partition wall. This could be avoided by using sealing strips of appropriate material to fill the gap between the partition wall and the column wall, which additionally can compensate for common shell-diameter deviations. In critical sections, like feed and product draw-off zones, welding a short section of partition wall could be considered as a safe measure. However, without enough experience in this respect, separations involving parts-per-million (ppm) and parts-per-billion (ppb) purity requirements may require welding of the partition wall over its entire length, which is more demanding and costly than no- or partial-welding approaches. One should note that even in case of a non-welded partition-wall installation, fixing liquid collectors and distributors will require a certain amount of welding activities, including the partition wall in redistribution sections, as well as rings and other local points on the column walls needed for auxiliary-equipment-fixing purposes.

Figure 9 shows a drawing illustrating the pressure drop situation in partitioned sections of the DWC shown in Figure 7. The pressure drop balances according to Equations (1) and (2) need to be arranged for the most representative operating condition during the design phase. The inevitable differences in individual pressure drops of packed beds in parallel sections are balanced by adjusting the free area of liquid collectors accordingly. As seen in Table 2, the pressure drop associated with operating packed single- and multi-partition wall DWCs is rather low. Details on hydraulic design of these configurations can be found elsewhere [*20*].

For those reluctant to consider the four-product DWC shown in Figure 7 as a new design, the associated uncertainties and potential risks could be lessened if the required arrangement would first be tested in a revamp of an existing column sequence. Where appropriate, transforming an existing three-column sequence into a DWC would allow energy savings equivalent to that achievable in new designs [*21*]. Indeed the economic and environmental incentives are so strong that a four-product DWC should definitely be considered as a retrofit option for existing three-column sequences.

Revamp and retrofit options

As previously mentioned, revamps of conventional distillation columns into a DWC have been realized in practice; however this was in natural situations, namely, with conventional side-product columns [*10, 13, 14*]. However, this could also be done with common two-column sequences [*21*] with the same effects, that is, expected energy savings accompanied by a considerable capacity increase. One should not forget that the reduced energy requirement is equivalent to the reduction in boil-up rate — in other words, a correspondingly reduced vapor flowrate. This implies a reduced shell diameter in new designs, and in case of existing columns, ensures a corresponding capacity increase. If original columns contain trays and these could be replaced with structured packings, then the chance is large that all required stages will be accommodated in one shell. This means that one of the original columns transformed into a DWC would replace two conventional columns, leaving one column and auxiliaries available for other purposes. If the same top pressure is used, a packed DWC will have a much lower bottom pressure and temperature; that is, an increased vapor volume, which means that the bottom stage will be limiting and will dictate the extent of the potential capacity increase. However, this concern is the

Source: Dejanović et al.
Chem. Eng. Process 68 (2014), in print

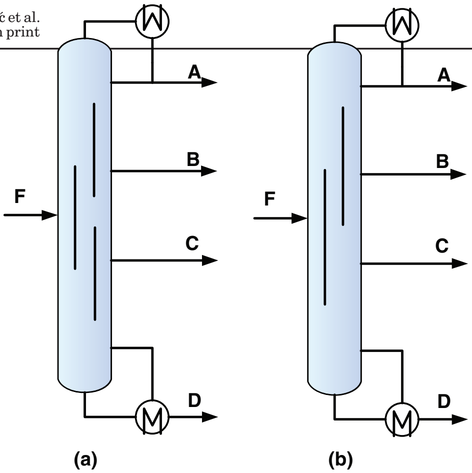


FIGURE 6. **A fully thermally coupled column four-product DWC is shown here with three partitions (a), and a simplified, two partitions equivalent of it (b)**

same for typical column revamp considerations.

If capacity increase is not a primary goal, then it is more probable that all stages could be accommodated within the available column height. For example, a larger surface area packing could be used. In the worst case, the required stage count could be distributed over two existing shells connected in series. This is also an option if trays need to be installed in a DWC, and advanced tray types could provide either higher capacity or higher efficiency, depending on the situation.

So a DWC is equally suitable as a retrofit option, and this is not limited to conventional three-product situations only. As mentioned before, energy savings will be equivalent to that expected in a new design, and this may be even above 50% if a three-column sequence would be redesigned to accommodate a four-product DWC. In this case, two shells should be sufficient to accommodate the required stage count, but, even with such a large reduction in boil-up ratio, it is hard to expect that a capacity increase could be obtained. The problem with four-product separations is that the pressure and temperature spreads are rather large and that operating pressures of individual columns in a conventional three-column sequence may differ to such an extent that lower pressure columns may become a bottleneck.

However, the situation is not hopeless because in such a case it can prove that a third, lowest pressure column could be used and connected in parallel to a second one to accommodate increased vapor traffic. The lower the boiling range of components in the feed mixture, the larger is the probability that both a new design and a retrofit DWC will be an attractive alternative for the conventional sequence. Regarding column design and rating work required, the number of options is large, but, as demonstrated elsewhere [*20, 21*], the predictive models introduced and used in our simulation studies are a suitable tool for such purposes.

If we consider the same aromatics plant base case (Figure 5, Table 1), then in the case of a revamp, we need only to accommodate the internal configuration as required in new design (Figure 7) into two existing shells. Columns 2 and 1 from the original sequence (Figure 5) were designed to operate with an overhead pressure of 2.5 and 1.7 bar, respectively. Both have an internal diameter of 2 m. The former was equipped with 59 and the latter with 61 sieve trays. Considering the utilized tray spacing, two shells of columns 2 and 1 connected in series provide a total active height (70 m) that is well above that required in the new DWC design (64 m, equipped with B1-350MN packing [*19*]). This is a comfortable situation that provides some flexibility. For instance, a coarser packing to accommodate increased vapor volumetric flowrate could be used in the lower pressure column. This, however, was not needed in the present case.

Figure 10 shows the result schematically, that is, the layout and internal configuration of the four-product DWC arranged using two available columns connected in series. The main feature of this revamp is reflected in the fact that each of the two shells contains only

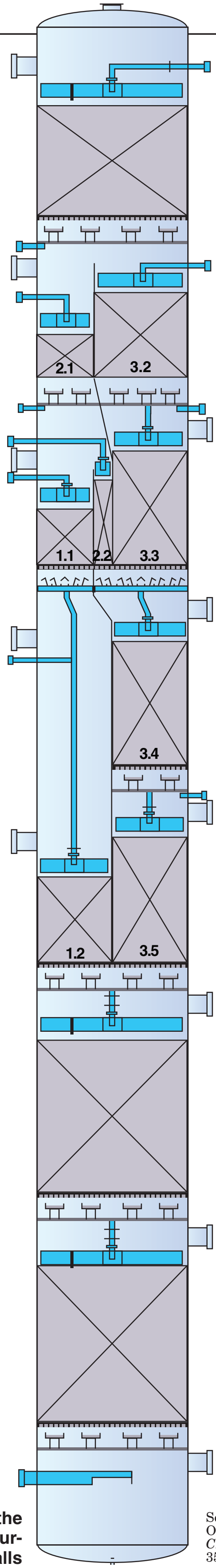


FIGURE 7. **This diagram shows the details of the internal arrangement of the four-product DWC with two partition walls**

Source:
Olujić et al.,
Chem. Eng. Technol.
35 (2012) 1392-1404

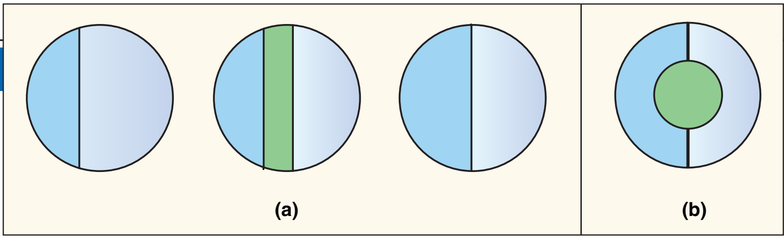


FIGURE 8. Presented here are the cross-sectional areas of partitioned sections as encountered in the four-product DWC shown in Figure 7 (a), and an alternative layout for column segment with three sections in parallel (b)

one partition wall. In other words, in the present situation, it appeared possible to avoid having three sections in parallel, which reduces construction and operation (one vapor split eliminated) effort to the level required when dealing with conventional three-product DWCs.

This was achieved by simply placing the prefractionator rectification section bed, which is in the new design on the level of the middle and main column sections, into the top of the high pressure column. This, in turn, allows significant enlarging of the cross-sectional area of the middle and main column sections that are placed in the bottom of the low pressure column. This appeared to be sufficient to compensate for expansion in vapor volume associated with a drop of 0.7 bar in operating pressure. A more detailed elaboration of this revamp case, indicating a rather short payback time (around 1 year), can be found elsewhere [*21*]. With energy savings turning into gains in the second year, a significant increase in profitability of this and similar plants could be expected.

Although the above gains are the results of preliminary evaluations, they are highly encouraging and provide incentive and motivation for a more detailed engineering step, namely, to identify and consider additional complexities and constraints associated with such a revamp, which could emerge as a reason to avoid it. First of all, the time available for such a revamp may be insufficient to arrange modifications of two existing tray columns in order to accommodate a packed DWC. Trays and tray support rings need to be removed, which is a routine but demanding and time-consuming activity inside the shell. Also, to accommodate such a complex configuration with packings and auxiliary equipment, a lot of local welding inside the shell will be needed to provide the required structural strength and support for numerous packed beds, liquid collectors and distributors. Utilizing a non-welded partition wall would minimize effort and time needed to install partition walls and packed beds in a quite confined space.

Also it is certain that a number of additional manholes will be required to allow installation and access to redistribution sections for future inspection and maintenance, as well as nozzles for feed, side draw-off, and for liquid and vapor traffic between the two columns and instrumentation. Also, the pressure drop associated with the transport of vapor from the first into the second column has not been accounted for as a part of pressure-drop balance determining the vapor split in the first column. This and other potential uncertainties need to be evaluated properly and accounted for during detailed process and mechanical design phase.

Indeed, the methods developed to allow conceptual design and detailed dimensioning of packed three- and four-product DWCs can be used to get a quite realistic picture of a DWC. However, each case is different and a thorough detailed technical analysis is required to see whether a new design or a revamp is a good option.

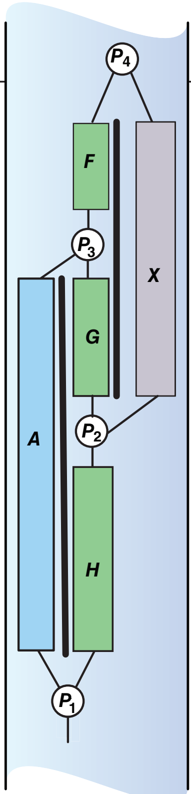
Closing thoughts and outlook

As mentioned before, a DWC is an unusual distillation column that uses conventional equipment in a complex arrangement, which introduces additional difficulties and uncertainties related to design and operation. Going from well-established three- to less known four-product separations makes everything more difficult, and potential constraints need to be evaluated properly. These constraints, however, may differ for new designs and revamps, as well as for packed and tray columns.

If we consider a new design, then a DWC will always be taller than any of the individual columns from the original sequence. In demanding separations, a rather tall column may be required, which, in conjunction with a small diameter (capacity), becomes a mechanical design and installation concern. On the process side, this means a larger pressure drop, which dictates the temperature spread between the top and bottom. This will be much more pronounced in a trayed compared to a packed DWC, and will depend on the spread of boiling points of the feed mixture. This implies that close-boiling mixtures, similar to that considered in our base case, lend themselves better to separation in a DWC than wide boiling mixtures. C1 to C5+ components, as encountered in natural-gas-liquids (NGL) treating and ethylene manufacturing plants [*22*], are good examples.

If single-pressure operation is not feasible, there are a number of alternative energy-saving options to be considered. In a four-product case, a common, three-product DWC could be connected in series with a conventional column. In three-product situations, the prefractionator and main column side could be accommodated in two thermally coupled shells operated at different pressures. This will ensure the same energy savings, but in a less cost-effective way. Another, less efficient but still highly rewarding alternative could be a pressure cascade, with a high-pressure condenser serving as a low-pressure column reboiler.

The temperature spread between the top and bottom becomes a problem if this requires a switch from cheaper to more expensive cooling or heating media. Unlike conventional columns, DWCs also exhibit a lateral temperature gradient in partitioned sections, which if excessive (say above 30K) may become a problem. Heat transfer across the partition wall may adversely affect the performance of both trayed and packed columns. In trayed columns, excessive vaporization can occur on the tray deck and in the downcomers. The only remedy is to consider



Source: Olujić et al., *Chem. Eng. Technol.* 35 (2012) 1392-1404

FIGURE 9. This diagram is a schematic representation of the pressure drop situation as encountered in partitioned sections of the four-product DWC shown in Figure 7

$$\Delta p_H + \Delta p_G = \Delta p_A \quad (1)$$

$$\Delta p_G + \Delta p_F = \Delta p_X \quad (2)$$

providing sufficient insulation in the critical zones. In columns using structured packings, heat transfer across the wall can be reduced to an acceptable level by using high-quality wall wiper systems, which not only center the packing inside the column but also remove any liquid running down the wall. By this method, no liquid on the cold side can evaporate, and heat flow across the dividing wall is drastically reduced when no vapor can condense on the hotter side.

Regarding the potential for mechanical damages due to thermal stresses imposed by welding and inevitable expansion (potentially deformation) of the partition wall, a non-welded wall is a much better option and should be considered first. However, the existence of a gap between the partition wall and column walls is a potential threat for the process side. During process and mechanical design, care should be taken to prevent vapor or liquid (or both) from going to the wrong side of the partition wall, which could lead, in the worst case, to irreparable product contamination. This is certainly a serious concern when ultra-high purity separation of main products is required.

Pressure gradients may develop if packed beds on the prefractionator side are shorter than those on the main column side, forcing a fraction of vapor to penetrate through the gap between the partition and column walls. A practical solution would be to install proper sealing means, and if in doubt, to combine sealed non-welded parts with welded ones, the latter being considered for critical sections, for instance, feed inlet and side product draw-off zones. Two-phase feeds are a concern and proper provisions need to be installed to avoid impact of any of the phases on the partition wall.

A DWC-specific design and operation concern at this stage of technology development is the control of the vapor split, which becomes a major challenge in the case of energy efficient, multi-partition, four-product DWC configurations. Designs are made for a certain operating condition, and the required vapor splits can be assured by dosing the amount of flow resistance for a given situation, for instance by choosing the most appropriate fraction of free area of liquid collectors [*20*]. However, to allow proper response to common fluctuations in feedrate and composition, adequate provisions for adjusting the vapor flow resistance in parallel sections are needed [*18*].

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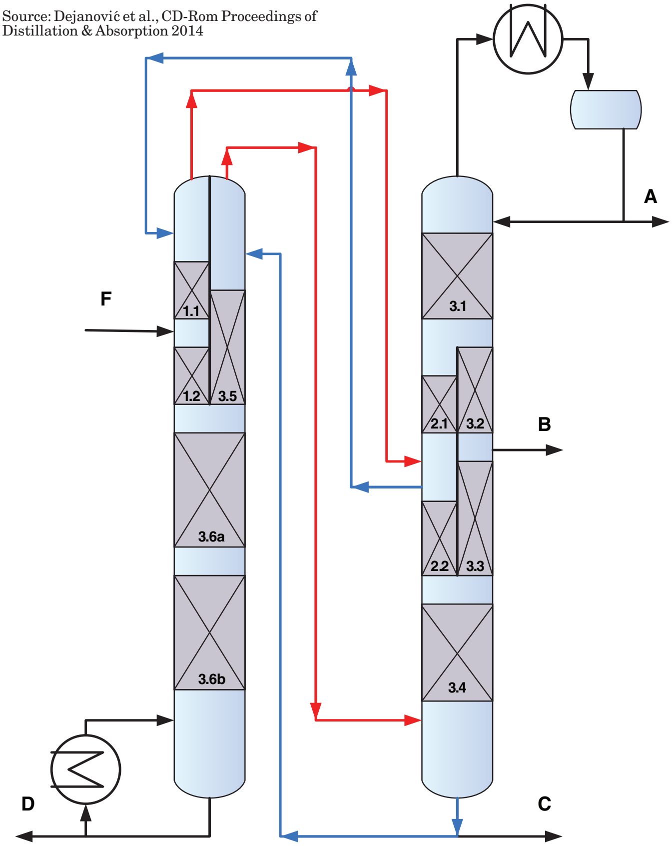

FIGURE 10. This diagram is a schematic representation of a four-product DWC arranged using shells of two existing columns (C2 and C1 from Figure 5)

Inexperienced practitioners may have concern or additional fear of being confronted with unexpected and uncontrollable operational difficulties due to fluctuations experienced in their plants. This is probably so, but the control of a DWC with its compactness (that is, an open structure with short distances for ascending and descending vapor and liquid) should be easier compared to the effort and equipment used in conventional sequences. The challenge is to find the right control strategy for the given case. Concerning four-product separations, control specialists are convinced that available knowledge applied in conjunction with the state-of-the-art computerized control systems will enable close to optimal operation. To enable full energy savings in four-product separations, a DWC should have the capability of active vapor split control [*18, 23–25*].

Development of effective devices for this purpose is a challenge. However, in some situations, like in our retrofit case with the DWC arranged in two shells connected in series, the control valves could be placed in vapor lines. In case of a DWC incorporating a partition in the top of the column [*18*], the condenser duty could be used for this purpose.

Implementing these and other techniques proven in other complex distillation design and revamp situations may lead to effective solutions and pave the way to a wider implementation of the most sustainable among distillation technologies — DWC technology. To begin with, a four-product DWC may be considered to be a highly interesting, cost-effective retrofit option for process industries confronted with the short-term need to significantly reduce energy usage and greenhouse gas emissions in their plants. Some daring on the user side is required. ■

Edited by Gerald Ondrey

Dedication

Dedicated to Dr. Gerd Kaibel, on the occasion of his 70th birthday!

Authors

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Distillation Column Thermal Optimization: Employing Simulation Software

Applying process simulation software in distillation-column design and operational analysis can lead to significant reductions in operational and maintenance costs and improved column performance

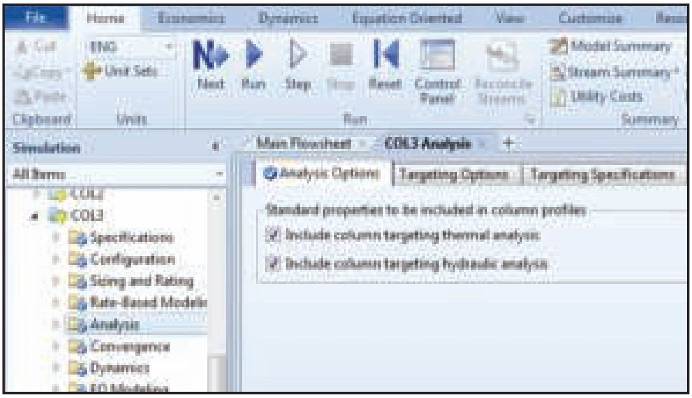

FIGURE 1. Thermal and hydraulic column analysis in advanced process-simulation software can be initiated with a mere check mark selection

Irina Rumyantseva and Ron Beck
Aspen Technology

Several market conditions, including availability of light crude oilds in the U.S., low natural-gas prices and improving macroeconomics, are driving debottlenecking projects related to columns in both petroleum refining and chemical settings. Fortunately, the process-simulation tools that can be used to perform the front-end of these projects have advanced significantly in the past several years.

Distillation columns present one of the most challenging design and operational challenges in most chemical and petroleum-refining processes. According to the U.S. Dept. of Energy, over 40,000 distillation columns are involved in plant operations in the chemical and petrochemical industries in North America, and they consume approximately 40% of the total energy used [*1*].

The hydraulics and phase behavior of chemicals within a column are complex and are dependent on a number of geometrical and maintenance factors, making it difficult to optimize column performance by hand calculations. Thus, industry is employing process-simulation software in order to optimize energy use in columns and pinpoint potential column modifications to implement in column design and retrofitting. Modern process-simulation software has all the tools necessary to maximize column energy efficiency, reduce utilities cost, improve thermodynamic driving forces to reduce capital investment, and aid in column debottlenecking. Engineers routinely use process-simulation software to perform thermal and hydraulic analyses (Figure 1) of columns [*1–3*].

This article focuses on applying software to perform thermal and exergy analyses of columns in conjunction with pinch analysis of the entire process for optimized conceptual designs and improved plant operations. One of the key values of using process-simulation software in column design and troubleshooting is the ability to screen and evaluate a variety of process-configuration options and operating conditions rapidly. As is also described in this article, some simulators can provide integrated economic evaluation so the costs of different alternatives can be contrasted. Further, steady state simulation can be augmented by modeling in a dynamic mode to look in more detail at the column behavior.

Thermal and exergy analyses

Process simulation can be applied when performing process design or retrofit analysis to identify potential design modifications to improve energy efficiency and reduce energy consumption.

The simulation compares column performance based on user inputs to the column performance in thermodynamically ideal column-operating conditions, which are determined theoretically, based on the practical near-minimum thermodynamic condition (PNMTC) approximation [*3*].

PNMTC assumes thermodynamically reversible distillation-column operation, where reboiling and condensing loads are evenly distributed over the operating temperature range of the column. This ideal column is assumed to operate at minimum reflux, has an infinite number of stages, and each stage has heaters and coolers with proper heat loads, so that the column-operating line coincides with the equilibrium line at any given stage. This approximation also accounts for losses and inefficiencies caused by column-design parameters, such as pressure drops, multiple side-products and so on.

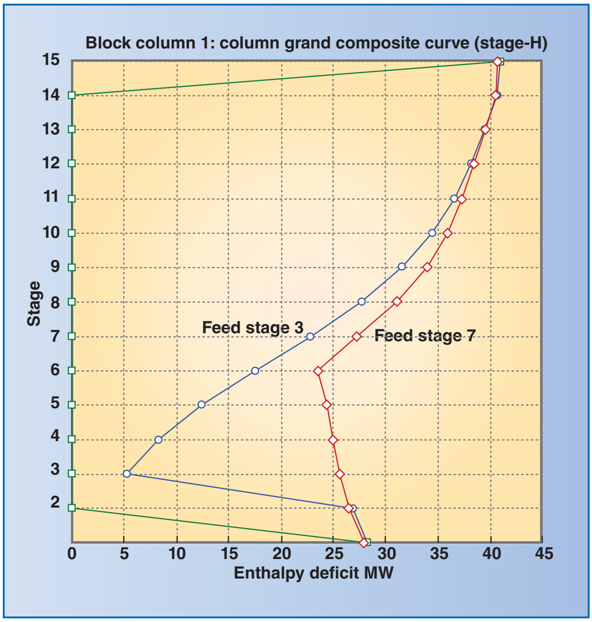

FIGURE 2. An example of using CGCC (S-H) to compare two design options with different feed-stage locations: stage 3 versus stage 7 (Green is the actual profile, red and blue are the ideal profiles)

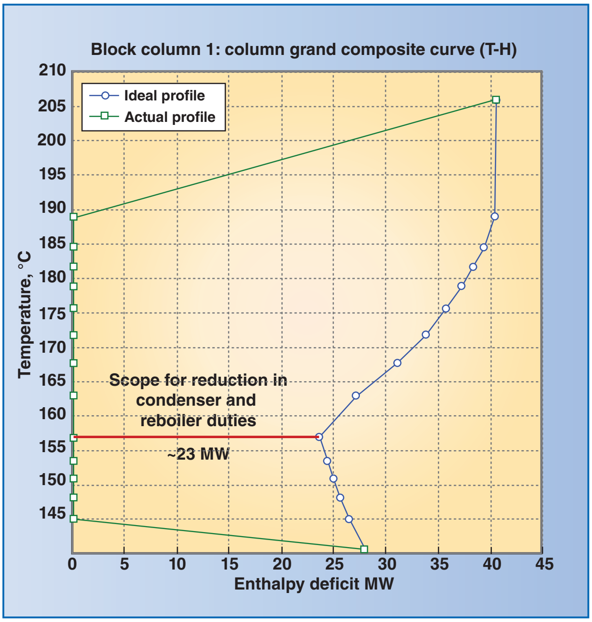

FIGURE 3. This CGCC (T-H) illustrates the duty reduction potential for design option 1

For each stage of the column, the software simultaneously solves equations for equilibrium and operating lines for automatically selected light and heavy key components [*1–3*].

Software generates stage-versus-enthalpy (S-H) and temperature-versus-enthalpy (T-H) profiles for a column that represent the theoretical minimum cooling and heating requirements in the temperature range of separation. These curves, called column grand-composite curves (CGCC) are used to identify potential objectives that can be accomplished by various column modifications [*1–3*].

In addition to thermal analysis, software can be used to perform exergy analysis. Software calculates exergy loss at each stage of the column, accounting for all material and heat streams entering and leaving the process. Exergy loss profiles are generated as a result, and they can be used to study how certain factors, such as momentum loss (pressure driving force), thermal loss (temperature driving loss), and chemical potential loss (mass-transfer driving force), affect the losses in work potential due to the irreversibility of real processes [*1–3*].

Using thermal analysis results

Engineers use the CGCC and exergy loss profiles, generated during thermal analysis, to analyze potential modifications to columns [*1–3*].

The CGCC are used to analyze how energy efficiency can be improved by a number of column modifications, including changing feed location, reflux ratio modifications, heating or cooling feed conditions, and adding a side cooler or heater. Software can produce the CGCC for temperature versus enthalpy, and stage versus enthalpy with a click of a button.

Exergy loss profiles are also easily generated to analyze exergy loss at different stages or temperatures, and these plots can be generated with a click of the button as well.

Stage-versus-enthalpy plots are useful in identifying opportunities for feed-stage location modifications. Engineers can easily identify irregularities that resulted from incorrect feed placement with the obvious projections at the feed location (pinch point) on the stage-versus-enthalpy CGCC (Figure 2). These projections are a manifestation of a need for extra local reflux to make-up for the unsuitable feed placement. A feed can be introduced either too high up in the column, or too low in the column, resulting in a sharp enthalpy change on the condenser or reboiler sides on the S-H CGCC, respectively. This will guide engineers in whether it is most appropriate to place the feed stage down or up the column, in order to eliminate such distortions and reduce condenser and boiler duties. Figure 2 compares two design options with feed stage located at stage 3 and stage 7. The S-H CGCC shows a noticeable projection on the condenser side at the pinch point located between stages 2 and 3. The corrected S-H CGCC that resulted in moving the feed stage down the column is also shown in Figure 2 [*2*].

Temperatures versus enthalpy plots are useful in identifying opportunities for reflux-ratio modifications. The potential for reductions in condenser and reboiler heat duties is characterized by the horizontal

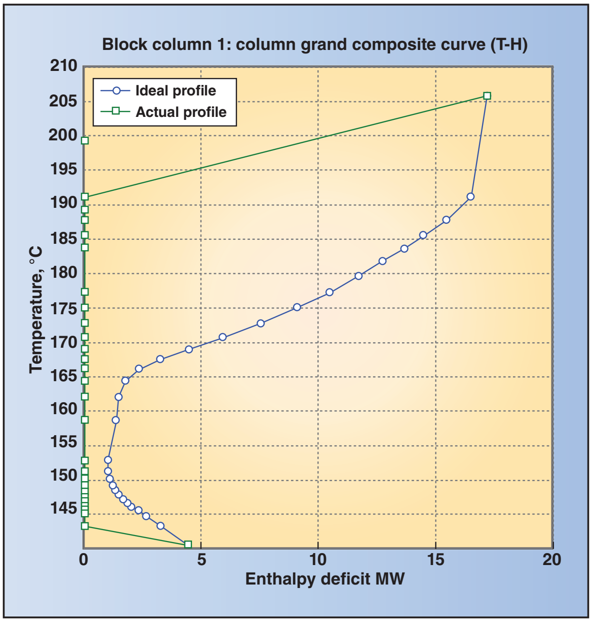

FIGURE 4. This CGCC (T-H) illustrates the duty reduction potential for design option 2. Note the much slimmer duty reduction potential, as compared to Figure 3

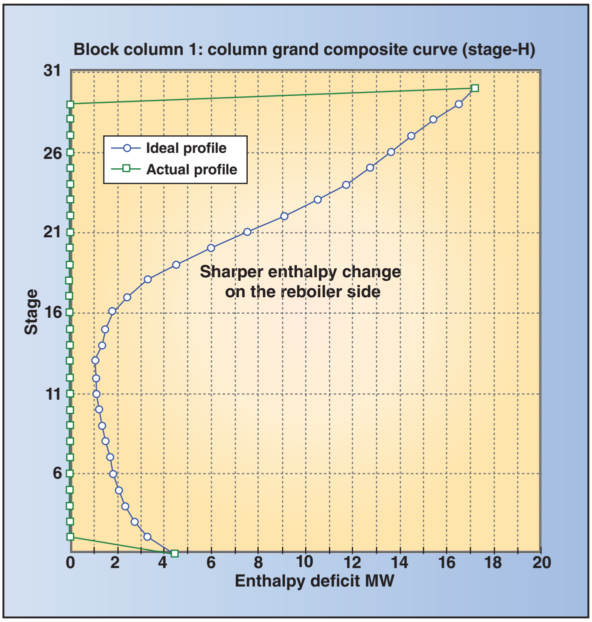

FIGURE 5. This CGCC (S-H) shows a sharper enthalpy change on the reboiler side

gap between the T-H CGCC pinch point and the ordinate, which represents the surplus of heat during the separation process. In order to reduce condenser and reboiler loads, reflux ratio can be reduced, while increasing the number of stages to sustain an adequate degree of separation. Comparing Figure 3 and Figure 4 demonstrates how T-H CGCC are applied in evaluating different design options to see how reducing the reflux ratio affects the condenser and reboiler duties. They illustrate how changing the reflux ratio from 7.7 to 1.3, while increasing the number of stages from 15 to 30, results in a 23.5 MW reduction in condenser and reboiler duties [*2*].

Either S-H or T-H CGCCs can be applied in finding the appropriate range of modifications to the feed quality. T-H CGCC plots will display sharp enthalpy changes either on the reboiler side or the condenser side, depending on whether the feed is excessively sub-cooled, or overheated, respectively. It is also worth noting that changes in the heat duty of pre-heaters or pre-coolers will lead to analogous changes in the column reboiler or condenser, based on the same principle. Figure 5 displays a sharper enthalpy change on the reboiler side in the S-H CGCC plot, which would lead an engineer to a conclusion that design could benefit from adding a pre-heater. A table of the simulation software results is then used to examine the effects of adding a pre-heater, resulting in reduced reboiler duty to the temperature levels at which the hot utility (for the reboiler and for the pre-heating the feed) is required to be provided [*2*].

Even though feed conditioning is a more desirable way to reduce utility costs, adding a side condenser or a reboiler can also provide a way to accomplish this goal. The goal of placing a side reboiler or a condenser is to allow heating or heat removal using a cheaper hot or cold utility, respectively. Side condensing or side reboiling provides an external way to modify column design, and is typically used when it provides a more convenient temperature level. Analyzing the T-H CGCC plots helps identify the range for side condensing or reboiling. Engineers look at the area below or above the pinch point, that is, the area between the ideal and enthalpy profiles. A side condenser can be placed if there is a significant area below the pinch point, and a side reboiler can be used in the opposite case. Figure 6 illustrates a base case. There is a large area between the actual and ideal profile above the pinch point, which leads to a design modification of adding a side reboiler to the base-case design. The resulting slimmer area between the ideal and the actual profile is shown in Figure 7, where a side reboiler with a duty of approximately 6.5 MW was added at stage 22. The addition of the side reboiler not only leads to a reduction in the heat duty of the main reboiler, it also helps reduce the hot utility [*2*]. However, one should keep in mind the capital cost of adding a side reboiler or condenser.

Exergy loss analysis is a complementary tool that is used evaluate the design modifications mentioned above [*2*]. Exergy loss profiles for different design options can be compared to determine which design is optimal. Figure 8 compares two design options using exergy pro-

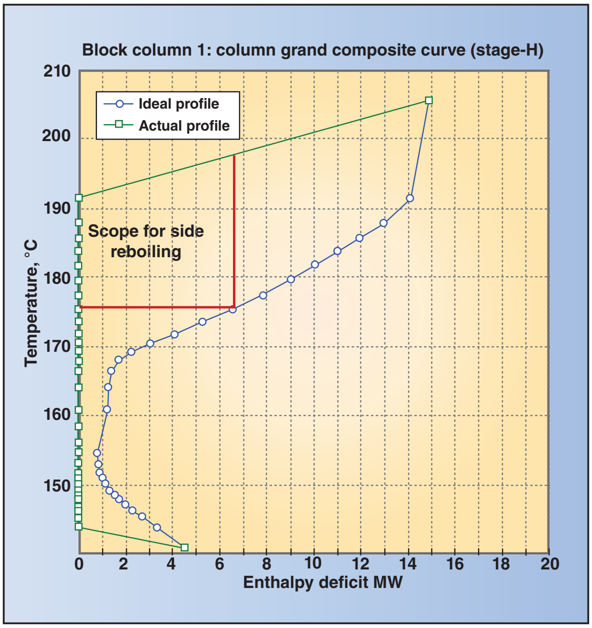

FIGURE 6. This CGCC (T-H) displays a large area between the actual and ideal profile above the pinch point, which helps identify an opportunity for design modification of adding a side reboiler with heating duty of 6.5 MW to the base-case design

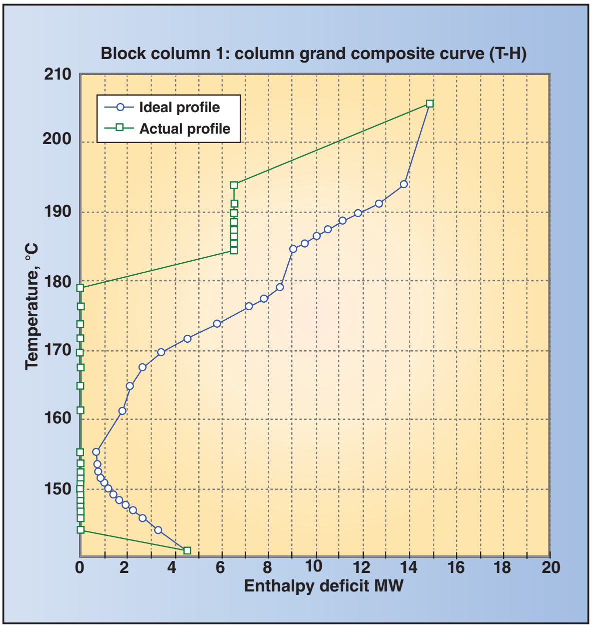

FIGURE 7. The CGCC (T-H) after an addition of a side reboiler that displays a much slimmer area between the ideal and actual enthalpy profiles

files: one with sub-cooled feed, and one with pre-heated feed. Note the higher exergy loss at the feed stage of Design 1, where the feed is sub-cooled. Design 2 shows a significantly reduced exergy loss by pre-heating the feed.

Hydraulic analysis can be used to together with the thermal analysis to remove possible bottlenecks in distillation processes and increase energy efficiency of the column [2], but that subject is not covered in this article.

Pinch analysis

Thermal analysis of column operation is an important tool in guiding decisions in column modifications; however, to achieve best results, it is important to use this tool in conjunction with and concurrently with other tools, in an "integrated context" [2]. When the process-simulation model is applied simultaneously, and is closely integrated with software that looks at the heat exchanger network (HEN) and performs pinch analysis of the entire process, taking into account other process heat sources and sinks, faster and more effective process modeling results can be achieved [2]. Software capable of performing pinch analysis can also be applied when analyzing the best ways to integrate column modifications with the plant utility system [2].

When used separately and iteratively, it is a painstaking task to rebuild the process heat network based on the process model. However, when used in an integrated mode, process modifications can be made and the HEN can be rapidly regenerated to look at the energy impact of various alternatives quickly. Other important factors to keep in mind when performing energy optimization of columns are the greenhouse gas (GHG) emissions. For example, installing a side reboiler might lead to increased GHG emissions, due to increases in utility consumption [*1*]. There are tools available to the industry that perform pinch analysis of the entire process, looking for ways to improve heat integration by comparing ideal design to the actual design and suggesting improvements. At least one commercial software tool (which incorporates an optimization algorithm that evaluates many heat integration opportunities and selects the best ones) can deliver suggestions for overall energy optimization with a click of a button, while computing utility cost savings potential and greenhouse gas emissions savings potential.

Such a tool automatically determines what types of utilities can be used for various plant processes and compares them to what is actually being used, displaying potential savings percentages. For example, a cooler might be set to use a refrigerant in the base case, but cooling water, a cheaper utility, can be used instead. Each utility is associated with a certain GHG-emission contribution, and that is calculated together with utility consumption as well. The user would just need to specify the appropriate utility costs and net carbon tax.

Evaluate design/retrofit options

Some of the design modifications resulting from the thermal column analysis are actually not beneficial to the process. For example, as

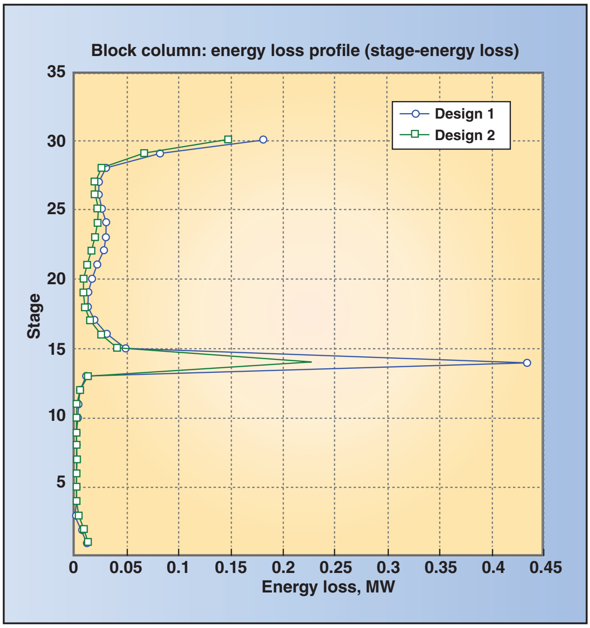

FIGURE 8. Exergy loss profiles for different design options. Note that Design 1 has reduced exergy loss at the feed stage when compared to Design 2

mentioned earlier, when the reflux ratio is reduced in order to decrease loads on condensers and the reboiler and save energy, the number of stages needs to be increased to ensure adequate separation, which will lead to increased capital costs. In order to make quicker, more optimal decisions, engineers can employ software that can estimate the capital and operating costs of the process, (using built-in rigorous as-built estimating models and sizing and mapping algorithms that operate against the process parameters) at a high enough level of accuracy to establish the tradeoffs between several proposed improvements, or between implementing the design modifications or not. A common example of using economic software in the decision process would be to decide whether to add a side reboiler or condenser, and in that context to compare the capital costs associated with new equipment to the reductions in operating costs.

Operability and profitability

There are a variety of changes and upsets that occur in process operations. In order to better control column operations and both achieve the desired product mix while minimizing energy, dynamic simulation is an excellent tool. The complexity of columns means that they are inherently not at steady state and can usually achieve better operations when the dynamics are well understood.

Some steady-state process simulators incorporate integrated dynamics-modeling environments, such that a steady-state process model can be used to quickly develop a dynamic model. Dynamic modeling of columns typically achieves better control strategies, better control of products, and optimization of energy use [*4*].

Concluding remarks

Columns often are operated below optimum operating conditions due to their complexity and the imperative to keep them within safe operating limits. The design, troubleshooting and debottlenecking of columns presents many opportunities to achieve improved control over product yields and reduction in energy consumption.

When the process model is used in conjunction with integrated pinch analysis, opportunities for energy savings can be examined and optimal process arrangements can be identified. Integrated economics can further enable consideration of capital and operating costs with respect to each design alternative. Dynamic modeling provides additional opportunities to identify operating strategies that will incrementally improve column operations.

Beyond the areas that have been discussed in this article, new innovations are around the corner, in terms of detailed modeling of columns and more convenient column-dynamics tools. ■

Edited by Gerald Ondrey

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A Safety Checklist For Laboratories

These nine best practices for managing change in laboratories can help ensure a safe workplace

Lori Seiler
The Dow Chemical Company

Laboratories, such as those used for quality control in a production environment and those in research and development, are an integral part of the chemical process industries (CPI). Everyday demands of business can easily overtake safety when it comes to setting priorities in the laboratory. Deadlines must be met. Samples must be analyzed. Questions must be answered — and quickly.

But even for the most experienced chemists and laboratory workers, safety must remain at the forefront. This is especially true when new chemicals, employees or equipment are introduced. Changes such as these are part of life in the laboratory, yet change represents risk. And as such, it is an element that must be thoroughly incorporated into every CPI laboratory's safety plan.

Read on for nine best practices — from identifying hazards to communicating effectively — to ensure that your laboratory is as safe as possible amid inevitable and ongoing change.

1. Tackle change upfront

As the old saying goes, "nothing is constant but change." And that's doubly true for work in the laboratory. In fact, change defines chemistry. So how do we plan for it?

Take time upfront to carefully assess the impact that every change will have on safety, health and environmental issues. Laboratory operations designed for safety also generate better, more reproducible results, without placing people or equipment at risk.

All project changes that are made in the laboratory should be first evaluated for potential hazards. Having a process in place to evaluate and manage change is extremely helpful. Inviting others to get involved as you work through the process is smart, as well. Your supervisors, advisors, co-workers and environmental, health and safety (EH&S) experts can put their knowledge and experience to work by helping to identify potential hazards and offering ways to mitigate those risks.

2. Identify potential hazards

You can't manage what you don't know or understand. Using a change-management process, you can identify potential hazards and mitigation solutions associated with change. Reviewing predefined triggers — or typical changes that are known to create hazards — can help as you go through laboratory changes step-by-step. The triggers quickly highlight changes that need further consideration.

A Hazard Assessment Trigger Grid and Safe Operations Card (SOC) are two tools that can be used to identify potential hazards [*1*]. SOCs allow you to evaluate hazards as you plan your laboratory project, thereby helping to ensure that any potential hazards are fully identified and assessed early on. They also document appropriate operating ranges, conditions and emergency response in the event of an accident.

Documenting potential hazards and evaluating how you will mitigate the risks are key components in managing process change. This ensures that others know about the changes, as well as their potential hazards and impact. The more everyone in the laboratory understands, the safer the work environment in the laboratory becomes.

3. Rely on a second set of eyes

Your colleagues can often see what you can't. The truth is that we become so familiar with our own work that we often overlook the obvious. Inviting a co-worker or supervisor to be your second set of eyes during a change review can help identify and address potential issues.

When sharing your situation with a reviewer, don't just sit in an office and talk about your changes with the other person. Go where the action is, like the laboratory hood or bench. Tell and show your reviewers exactly what you will be doing (Figure 1). With everything set up and in sight, you and your reviewers may see things that can be modified to further enhance safety. Reviewers should ask open-ended questions to best understand the work to be completed and potential worst-case scenarios, as well as to

SAFETY INSPECTIONS: THE KINDNESS FACTOR

It is amazing what you can find when you take time to look, ask and connect with those around you. During times of change, which can introduce extra stressors into the environment, this element of connection becomes extremely important in ensuring that communication is clear and effective. This is true throughout laboratory work, but is notably important during inspections.

Inspections help identify and mitigate safety discrepancies, and they can be formal or informal, depending on what is needed. Yet inspections are more than checking off items on a checklist to see what is "good" or "bad." They are an opportunity to ensure that everyone in the laboratory clearly recognizes and understands what is needed to maximize laboratory safety.

In fact, one of the most important components of inspections is the interaction and dialogue that will take place between you, your co-workers and supervisor. That is why it is a must to make a personal connection during the inspection. Psychologist E. Scott Geller says that actively caring means practicing "systematic and purposeful acts of kindness to keep other people safe and healthy."

When you and your co-workers care about safety — and each other — you will want to learn how to improve. You will be actively involved. So create an environment in your workplace where people are free to ask questions and know how to escalate issues that become a problem. Make sure that everyone in the laboratory knows that no matter what, safety must be planned into the experiment every step of the way.

Finally, after taking the time for inspections and improvements, remember to recognize success. As improvements are made, or if a minimum number of safety discrepancies are found, let everyone know. Be loud and proud about your successes in incorporating new chemicals, materials, equipment and new people into your work environment. ❑

understand the layers of protection and safety measures in place to mitigate risks.

You'll find that both you and your project will benefit when you involve a variety of people with different expertise and experience early on. When considering who to approach for this role, seek to match your reviewers with the type of change that you're planning. For instance, if you are installing new equipment, get people who are familiar with that type of equipment. If you are using new chemistries, get people who are knowledgeable about those. Use their knowledge to your advantage.

An added bonus to the review is that this type of cross-functional involvement creates networking opportunities. You will get to know people throughout your department and in other functions, as well.

4. Understand the risks

When new chemicals enter the laboratory, the risks increase. This situation calls for special planning to account for how you will plan your experiment — including what equipment you'll use, how you manage your waste and decontamination considerations.

To provide an example, let's say that you are beginning new laboratory work that involves nanomaterials. Your preplanning research would tell you that these ultrasmall materials could be absorbed by the body faster than other materials, thereby resulting in greater exposure. Also, they may travel to internal organs that were not previously accessible to the larger-scale particles of the same material.

As part of the preplanning process, you would want to assess potential worker exposure to any nanomaterials that will be used by considering tasks that may potentially expose you or fellow laboratory workers to nanomaterials. You would consider the dustiness of the material, how it will be used, how much will be used, and the duration and frequency of the task.

Once the preplanning is finished, move on to safety equipment considerations. Will a fume hood be needed? Is your standard personal protective equipment (PPE) enough to keep you safe? Continuing with the nanomaterials example, you would want to ensure that you keep the materials off your skin and out of your lungs and eyes. As such, ventilation systems would be needed to capture and remove airborne nanomaterials before they are inhaled by workers. Depending on the scale of the operations, ventilated enclosures, local exhaust ventilation or other types of ventilation could be needed. Go through this planning process for any new material you introduce, devoting extra time to evaluate your safety when dealing with pyrophoric materials, hazardous chemicals, cryogenic liquids and reactive chemicals.

When considering disposal of new chemicals or materials, always be sure that different categories of waste are stored in different containers and are clearly separated, and that incompatible chemicals are stored separately. The laboratory is not the place for unexpected reactions.

5. Know your equipment

When a new material is introduced to the laboratory, new equipment often must be used. From fume hoods and glassware to gas cylinders, nearly every piece of equipment in a laboratory can pose a hazard when used inappropriately. Be sure to think about and plan for how you'll handle tasks like equipment set-up, maintenance and cleaning. The hazards associated with these types of support tasks (such as ergonomics, decontamination, energy control and more) are often underestimated.

Not only must you make sure that you are completely up to speed on the safest way to operate the equipment — especially if it's been some time since you've received training — but you also must ensure that others, including new employees, are up to speed as well. In the rush to find results for an experiment, shortcuts may seem appealing, but proper care always must be taken — even more so when change is afoot.

If you are uncertain about how to use a piece of equipment, seek out training. For quick refreshers, resources are available on a variety of topics [*2*].

6. Take care when working alone

On a busy day at work on a new project, you may be tempted to stay late to make additional progress. If you find yourself in this situation, you must first look at the work you'll be doing and evaluate its hazard potential before deciding that it is safe to work alone.

If what you're doing is classified as a high-hazard operation, it's never safe to work alone, even if special precautions are in place. Some examples of high-hazard operations include work with process plants, any equipment that compresses, and work that involves high quantities of flammable or extremely hazardous materials. These kinds of operations require two or more people, including a safety observer or someone who can provide immediate help in case of an emergency.

But even low-hazard operations come with risks. In general, low-hazard operations include routine analytical work, such as titration, handing samples for routine analysis, minor maintenance, general laboratory work and office work. These operations don't present any major risk to safety and are generally safe, as long as you have a plan in case of a problem. A mechanism like a lone operator alarm or emergency radio should be in place.

7. Practice good housekeeping

In the laboratory, everything you do, or don't do, makes a difference in the outcome of your experiments and your safety. That includes keeping the laboratory clean. Whether you're introducing change into the laboratory or not, you're much more likely to notice when something is amiss when everything is in order.

Use a checklist to perform inspections on at least a monthly basis. Ensure your space is free of tripping hazards, unused materials, excess paper and clutter. Check to make sure that the covers for drains and trench drains are in place. Also, pay special attention to surfaces — including benches, floors and operating equipment — to see that they are free of hazardous dust accumulation.

Part of your checklist should focus on safety equipment: Is everything in place and functioning as it should be? Be especially vigilant when it comes to personal protective equipment, respirators, eyewash, safety shower, fire extinguishers and telephone. Once your laboratory inspection is done, openly communicate any problems you see, especially unsafe practices and procedures. (See sidebar. p.55: "Safety Inspections: The Kindness Factor.")

FIGURE 1. Pre-startup safety reviews are an important tool to help ensure laboratory safety

8. Communicate clearly

Communication is critical to effective laboratory safety in any situation, but especially when any change is introduced to your laboratory. While this may seem obvious, poor communication is the reason for far too many laboratory accidents. That's why it is absolutely essential that you communicate with everyone who could be impacted by any change.

Your plans must always be shared with anyone who could be impacted by them. Be diligent about this. Discuss the experiments you will be conducting, the potential hazards, worst-case scenarios and any planned emergency response. As project owners, be receptive to the advice and safety improvements suggested by colleagues. As reviewers, interact and share your expertise in a way that influences safety best practices. The engagement should be a positive interaction where risks are identified and solutions to mitigate these risks are identified.

The aforementioned SOC is a great tool for helping to plan for and communicate potential hazards connected to process change. SOCs establish accurate communication between you and everyone else in the laboratory — and that is one of the most important things you can do to ensure a safe working environment.

9. Make change part of the culture

In order to ensure that change management is always part of the plan, a strong safety culture must permeate the laboratory. And while everyone is essential to the safety culture, it starts with leaders.

Experience shows that leaders who actively engage with their teams help deliver outstanding results and improved performance. They are able to build, strengthen and engage their teams. This is certainly true for safety performance. Even if you are not a laboratory leader, you have a big role in promoting leadership engagement. First, help your safety leader in identifying key systems needed, such as programs, practices, procedures and training. As your leader identifies key behaviors required to achieve the desired goals, be open and willing to adjust, use and champion those behaviors.

Change and safety are constant

Your personal safety, as well as the safety of your co-workers, depends on your commitment to managing change wisely. Remember that change is the main reason to stop and evaluate potential hazards. Whether you're changing chemicals, equipment or people, you can manage it successfully and safely.■

Edited by Dorothy Lozowski

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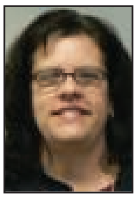
Author



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Cooling Towers: Managing Tighter Water-Discharge Regulations

Tightening regulations for cooling tower water-discharge quality are requiring plant engineers to evaluate enhanced treatment options, sometimes including zero-liquid-discharge systems

Brad Buecker
Kiewit Power Engineers

Historically, many large industrial facilities, including power plants, have relied on once-through cooling, in which the entire cooling water volume flows through the plant heat exchangers and then is discharged to the original source. However, the U.S. Environmental Protection Agency (EPA; Washington, D.C.) has, for over a decade, been developing regulations to protect aquatic life from impingement and entrapment at once-through cooling intakes. This development has essentially eliminated once-through cooling as an option at new plants. Rather, cooling towers now tend to be the preferred choice, with air-cooled condensers increasing in popularity.

Cooling tower blowdown

Subsequent to the passage of the Clean Water Act in the late 1960s, EPA began controlling industrial plant wastewater discharges per the National Pollutant Discharge Elimination System (NPDES) guidelines. In many cases, NPDES guidelines focused on a small core of primary impurities in wastewater discharge streams. The two most common for cooling water were pH (typical pH control range of 6.0 to 9.0) and residual oxidizing biocide at a common limit of 0.2 parts per million (PPM). These guidelines, or perhaps even more stringent limits, are still in place at virtually all facilities, but the EPA is currently preparing new national guidelines that will place limits on additional constituents. These new effluent-limitation guidelines, expected to be finalized in 2015, will include the heavy metals, chromium and zinc, with projected limits of 0.2 and 1.0 ppm, respectively.

However, the story does not end there. Individual states are allowed to develop their own discharge guidelines, as long as they are as stringent as those issued by the EPA. In many cases, states are promulgating tighter regulations that may place limits on some or all of the following additional constituents that are commonly found in cooling tower discharge:

- Total dissolved solids (TDS)
- Sulfate
- Zinc
- Copper
- Chromium
- Phosphate
- Ammonia
- Quantity of discharge

Concurrently, regulators recognize water as an increasingly scarce resource and are requiring some facilities to use alternatives to fresh water as cooling-tower makeup. Potential alternative sources include reclaim water from municipal wastewater-treatment plants and low-purity (untreated) groundwater. (This trend is particularly evident in California, where water rationing is becoming increasingly important). In the case of reclaim water ammonia, phosphorus, and organic material are often problematic constituents, and thus the cooling-tower makeup might require pre-treatment, such as ammonia stripping and phosphate precipitation, and organics removal by clarification.

As an example of the impact of

changing NPDES regulations, consider the changes required to meet the new guidelines at a power plant operated in the Southern U.S. Prior to 2013, the plant's NPDES permit primarily focused on pH and residual oxidanta. However, the new permit now imposes an average monthly limit of 1,200 mg/L TDS. Given that the TDS concentration of the makeup water sometimes reaches 400 mg/L, the tower cycles of concentration (COC) may be limited to three under the new regulations, whereas previously the tower was allowed to operate at a significantly higher COC (See the sidebar, right) for a brief discussion of the COC concept).

Another impurity that now receives more scrutiny is sulfate (SO_4). Managing sulfate can be particularly problematic with regard to the overall process chemistry of properly managed cooling towers, as sulfuric acid is commonly added to cooling-tower makeup to remove bicarbonate alkalinity and thus minimize calcium carbonate ($CaCO_3$) scale formation in the condenser and cooling system. The common treatment step follows this reaction pathway:

$$H_2SO_4 + Ca(HCO_3)_2 \rightarrow CaSO_4 + 2H_2O + 2CO_2\uparrow$$

However, tighter regulations on sulfate in the discharge stream may curtail or eliminate this common and straightforward method of scale control at some plants.

On a related note, phosphorus is also being banned in many waste streams [*1*]. Phosphorus serves as a nutrient that encourages plant growth. When released to open bodies of water, excess levels of phosphorus can initiate and propagate toxic algae blooms. The challenge for tower owners is that organic and inorganic phosphates are widely used for corrosion and scale control in cooling-water systems. To meet this challenge, a variety of all-polymer programs have emerged for corrosion and scale control, to minimize phosphate use.

As has been noted, some heavy metals are also on EPA's proposed upgraded NPDES list, with primary examples being zinc and chromium. State regulations may impose other limits. For the plant mentioned above, the expectations are that copper discharge will, by 2015, be limited to less than 30 parts-per-billion (ppb). According to Ref. *2*, copper limits are as low as 12 ppb in some parts of the U.S. At these very low limits, copper discharge can potentially be a problem for units equipped with copper-alloy condenser tubes. However, additional sources of copper, which often affect older wooden cooling towers, are the copper compounds that are used as wood preservatives. One possible solution is to replace older cooling towers with modern, fiberglass towers. Another possibility is to install a wastewater-treatment plant that includes a precipitation step to remove heavy metals.

These examples underscore the fact that at existing plants, the costs to comply with new liquid discharge guidelines may be significant. For instance, a switch to all-polymer chemistry in a large cooling tower to avoid strict limits on COC, or to eliminate phosphate in the discharge may result in annual cost increases in the six figures. The capital cost to install a treatment system to remove newly regulated impurities from the discharge can easily reach or exceed $1 million. Plus, the addition of waste-treatment systems adds complexity and operational costs to the plant over the lifecycle of the facility.

COOLING TOWER CYCLES OF CONCENTRATION (COC)

In a cooling tower, warm water from condensers or other heat exchangers is sprayed or is allowed to fall through uprising ambient air. Typically 65–80% of cooling is accomplished by evaporation of perhaps 2–3% of the circulating water into the air. At atmospheric conditions, the latent heat of evaporation is roughly 1,000 Btu/lb — so much heat is transferred by evaporation. As the water evaporates, minerals are left behind. Thus, the dissolved-solids concentration of the circulating water continually increases during tower operation. The cycles of concentration (COC) is simply the ratio of the dissolved solids concentration in the circulating water compared to the concentration in the makeup water. For example, if the circulating water has a chloride concentration of 250 ppm, and the makeup has a chloride concentration of 50 ppm, the COC is 5.0.

Unlimited COC is not possible, as eventually, the concentrating effects of evaporation will lead to scale formation by some of the minerals. So, periodically a portion of the circulating water is "blown down" to purge the system of dissolved solids and replenish the system with fresh makeup water. Very common is automatic blowdown based on continuous measurement of an easily analyzed property, such as specific conductivity.

The relationship between blowdown volume and COC is outlined in standard cooling tower texts. It is represented by the fundamenal equation:

$$BD = E/(COC–1)$$

Where:

BD = Blowdown rate, gal/min
E = Evaporation rate, gal/min

Thus, higher COC equates to lower blowdown rate. This can be very important, particularly if the blowdown must be minimized for discharge purposes or to conserve water. At low COC, any increase in the cycles of concentration greatly reduces the blowdown volume. This effect diminishes at higher COC values. ❑

Moving to ZLD

In addition to the impurities mentioned above, there is always the possibility that additional wastewater contaminants could be regulated in the future. For this reason, some experts recommend that plants consider a zero-liquid discharge (ZLD) process at the beginning of the project. However, ZLD is often rather complex. Perhaps the most "straightforward" ZLD disposal technique — albeit with a large caveat — is deep-well injection. The wells would have to be several thousand feet deep to avoid the possibility of the discharge stream ending up in the shallow groundwater sources that are used for residential purposes. While this concept sounds simple, experience has shown that some wastewater streams can generate scale within the well shaft, particularly as the water temperature rises further underground. High-pressure is generally required for this process, and if scale formation occurs, then capacity may decrease as the piping becomes more

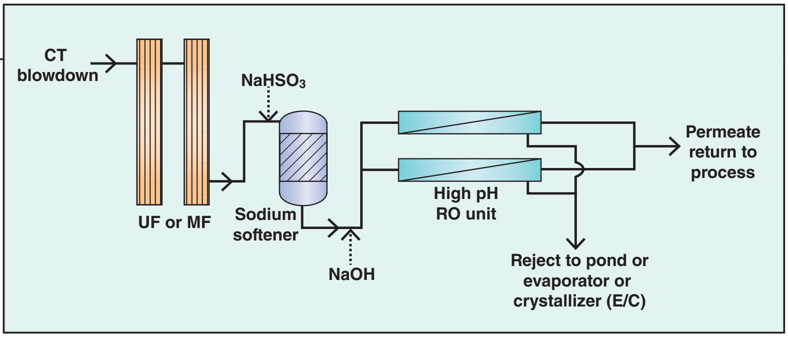

FIGURE 1. **Shown here is a generic outline of one emerging wastewater-treatment technology, which is discussed in the text**

and more constricted by deposits.

At facilities in arid locations that have a large land area, evaporation ponds may be sufficient to handle the wastewater discharge. However, these ponds must be properly lined to prevent seepage of the wastewater with its impurities into the underlying soil. And permitting may or may not be granted for such evaporation ponds. Alternatively, at sites that are strategically located, it may be possible to have the wastewater trucked off-site by a centralized waste-disposal company.

If none of the above options are available, thermal evaporation of the waste stream may be the only option to cost-effectively meet these stricter discharge limits. At a recent visit to a plant in the Southwestern U.S., the author observed a brine concentrator/crystallizer system that treats the entire cooling tower discharge stream. While the system is manageable, the inlet flowrate at full load is nearly 1,000 gal/min. The energy requirements are quite large, as are the regular maintenance costs to remove accumulated solids from the evaporation equipment.

To help minimize these two costs, many cooling tower operators are implementing treatment methods that can reduce the overall volume of the cooling tower blowdown and other waste streams from the plant. These may include microfilter and reverse-osmosis (RO) reject, plant drains, and service water discharge. An emerging technology for waste-stream volume reduction and increased water recycle is high-recovery reverse osmosis, as shown in Figure 1. Keys steps in this process are as follows:

- Microfiltration (MF) or ultrafiltration (UF) to remove suspended solids in the waste stream: This is a critical process to prevent suspended solids from fouling RO membranes
- Sodium bisulfite ($NaHSO_3$) feed to remove residual oxidizing biocides: This is also critical to remove oxidizing biocides that would degrade the water softener resin and RO membranes
- A sodium softener to remove calcium and magnesium: Otherwise the downstream equipment would suffer from calcium carbonate and magnesium silicate scaling
- Sodium hydroxide injection to elevate the pH above 10: The combination of hardness removal and pH elevation keeps silica in solution
- Two-pass RO treatment

Under proper conditions, the RO recovery rate may reach 90%. The RO permeate is recycled to the plant's high-purity makeup water system or other locations. However, while the process appears straightforward, a number of lessons have emerged regarding this technology in actual application. One of the most notable is that some standard water-treatment chemicals, particularly cationic coagulating and flocculating polymers may foul MF, UF and RO membranes. The difficulty arises from the fact that most membranes carry a negative surface charge while many of the polymers employed for water treatment have a cationic charge. As a result, residual polymer will coat the membranes.

A similar phenomenon has been observed with MF or UF systems that are installed in makeup water systems downstream of a clarifier. Inexperienced designers and plant personnel often do not recognize that MF or UF are most effectively used as a replacement for clarification — not as a polishing process for the clarifier.

At a combined-cycle power plant in the Northwestern U.S., another interesting initial difficulty occurred in application of this process. Normal MF or UF operation is a cyclic process with permeate production during a user-established period (20 minutes is common), followed by a backwash period of one minute or so, followed again by permeate production and so on. Typically, a small port,ion of the permeate is collected in a separate tank at the beginning of the process for use during the backwash step.

However, most modern MF and UF units are now equipped with automatic, chemical-enhanced backwash (CEB) systems. After a certain number of regular backwash cycles, a CEB backwash is automatically initiated. First the membranes are cleaned with a dilute caustic or bleach solution to remove organics and microbiological organisms.

This is followed by a rinse step, and then a dilute citric-acid wash to remove iron particulate matter. When the UF in this particular application was first commissioned, the membranes quickly developed a layer of calcium silicate scale during the CEB caustic stage. The higher pH had greatly reduced the silicate solubility, producing scale that was very hard to remove. In this application, the magnesium concentration of the blowdown was relatively low — otherwise magnesium silicate deposition would also have occurred (this was observed at another facility using this setup along with a CEB procedure). To address this, the operators made a switch to softened water as the backwash supply for the CEB procedure.

This case and others clearly emphasize that pilot testing should be strongly considered before installing such systems. Some water-treatment equipment vendors have suggested the use of upstream multi-media filters to help condition the blowdown stream, but direct observation has shown that these filters may be completely ineffective in preventing chemical fouling of membranes, for the reasons offered here.

Another important factor to consider with these treatment systems regards redundancy, either via additional storage capacity or standby equipment. With a properly operating system, the final waste stream is obviously very much reduced. But if the system goes offline for any reason, the entire blowdown volume plus additional plant wastewater streams can be too much for the final treatment process, particularly if it involves thermal evaporation.

Summary

Once-through cooling is no longer an option for many power plants and chemical process industries (CPI) plants. Most often, cooling towers are the preferred choice, although air-cooled condensers are appearing more frequently. For new and existing plants with cooling towers, increasingly stringent effluent guidelines are requiring plant owners, operators, and technical personnel to evaluate water and wastewater treatment modifications and additions. Many factors will influence the final technology selection, including the following:

- States may impose guidelines beyond those set by EPA
- Regulations are becoming more stringent for additional wastewater constituents, such as TDS, sulfate, phosphate, ammonia and some heavy metals
- Restrictions on discharge of specific impurities, such as phosphate, can greatly influence the choice of cooling-tower treatment program. For many operators, all-polymer treatment programs are emerging as a preferred alternative
- Discharge chemistry control may, in part at least, have to be addressed by modifications to the water-treatment steps taken for the makeup water
- Increasingly, plants in some areas of the U.S., either from a mandate or by necessity, are selecting reclaim (gray) water for makeup. These supplies often have variable water quality, which greatly influences cooling tower operation and the ultimate chemical makeup of the blowdown
- Installation of wastewater-treatment systems may be required to comply with new guidelines
- It is quite possible that other wastewater constituents may be regulated in the future, such as additional salts, heavy metals, chloride and bromide, which are under scrutiny. Selection of ZLD as a proactive measure can prepare a plant for such future eventualities
- Installation and operation of a wastewater-treatment system to achieve ZLD is not a simple process. Many factors can influence system performance, including the following:
  - The variable quality of the plant makeup water, especially if unreated or reclaim sources are the supply
  - The potential for fouling of the wastewater-treatment system that can arise from standard chemicals that are widely utilized for water treatment
  - Change in the final waste stream that comes from the primary treatment process. If such techniques as evaporation ponds or deep-well injection are not possible, thermal evaporation may be the only choice. ■

Edited by Suzanne Shelley

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Dry Separation Methods

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Separating bulk solids via air classification, screening or gravity separation is ubiquitous in many industries — an understanding of these processes is crucial to solids-handling engineers

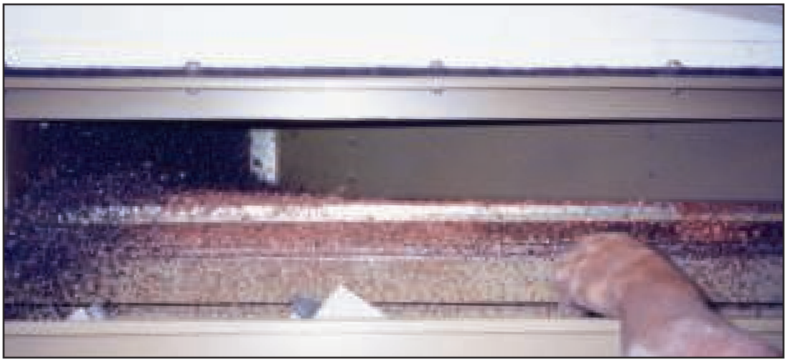

FIGURE 1. A common dry separation process is the recycling of heavy metals, such as copper

The chemical process industries (CPI) have many applications that require classifying or separating solid materials. Examples of separation or classification processes include those operations that attempt to isolate specific material fractions according to particle size, scalp off the coarse fraction of a material stream, de-dust the fine fraction of a material stream or remove the contamination from a material stream. For instance, dry separation is required in recycling processes for heavy metals, depicted in Figure 1. Dry separation methods can basically be broken down into three main types of mechanical separation procedures: air classification, screening and specific-gravity separation.

Process engineers are routinely challenged with the ubiquitous problem of how to most effectively and efficiently perform particle sizing, along with addressing concerns about the removal of unwanted contaminants from a material stream. This article provides background on the different techniques and equipment used for dry separation, and also guides engineers in addressing some specific dry-separation issues.

Air classification

The development of air-classification equipment, like most processing equipment, is an ongoing process. As such, newly introduced equipment has been designed to offer better classification efficiency with the ability to produce increasingly fine products. Rising demand for finer products and more closely controlled particle-size distributions are the driving forces behind the development of high-efficiency, centrifugal-type air classifiers. In recent history, almost all design improvements have been the result of an increased understanding of aerodynamic principles, as well as particles' behavior in an airstream when subjected to various forces. Other areas of concern for classifier improvements involve achieving greater classification efficiency while delivering higher capacities and finer products. These improvements result in greater control over the classification process, because improved designs tend to be more sensitive to changes in process parameters, such as rotor speed, air flowrate and particularly feedrate.

Despite the complexity of air-classification equipment, all air classifiers operate under the same basic laws of physics. There is an established balance of forces — gravitational, centrifugal and drag forces are integral to air-classification processes. It is difficult to precisely evaluate the interaction of all the forces within the classifier and their effect on the particles. However, centrifugal force (Fc) and drag force (Fw) are the two main opposing forces under which particles are subjected. Expressions for centrifugal and drag forces are given in Equations (1) and (2), respectively.

$$Fc = d_p^3 \times P_p \times R \times n^2 \times \pi^3 / 5{,}400 \quad \textbf{(1)}$$

$$Fw = d_p \times 3\pi \times \eta g \times Vrad \quad \textbf{(2)}$$

where:
d_p = particle diameter
P_p = particle density
η_g = viscosity of the gas (air)
$Vrad$ = radial speed of the gas (air)
R = radius of classifier wheel
n = speed of classifier wheel (rpm)

In general, the centrifugal forces within the air classifier are typically imparted by a high-speed rejecter rotor, also known as a classifier wheel. The particles that are introduced into the classifier are accelerated by the classifier's mechanically driven rotor. The rotor allows for very high air and particle acceleration, resulting in high centrifugal forces. The ability to disperse the particles through centrifugal spin is of the utmost importance in achieving efficient air classification. The coarse particles are affected by centrifugal forces and move in the outward direction. As they move toward the outer edge of the vortex, their peripheral velocity will decrease and gravity will overcome the centrifugal and drag forces, dropping the coarse particles out of the airstream. The addition of air from an external fan assists in the dispersion and suspension of particles. The drag force of the airstream has a greater affect on fine particles, because of their lower mass. In this case, the drag force is greater than the centrifugal force on the particle. Thus, the fine particles are swept out of the classifying zone by the airstream, where they are held in suspension around the rotor. The airstream is used to wash the fine particles out of the material stream and carry them to the classifier wheel, where they pass through the rotor and are discharged as fines. The air introduced from the external fan must be balanced with the solids loading to achieve the optimum air-to-solids ratio.

These two process variables, air and solids loading, will be different for each material, depending on the material's specific gravity, particle shape and surface area. Once determined, control over a product's particle size is achieved by controlling the speed of the classifier rotor. The cut point can be precisely controlled by increasing or decreasing the rotational speed of the rotor. Typical applications for this type of air classifier include: making size separations in the range of 5–45 µm (325 mesh); de-dusting of very fine particles; and generating narrow size distributions. The air classifier will classify the particles by surface area primarily; density classification is secondary. In general, the classifier will produce a more efficient separation when there is an overall broad distribution of particles in the raw feed. When the raw feed has a very narrow particle-size distribution, it becomes difficult for the classifier to differentiate between near-size fines and near-size coarse particles.

Screening equipment

Like air classification, screening or sieving involves the separation of dry granular solids according to particle size. Screening equipment is used in almost every process that handles dry particulate matter. Screening requires relative motion between the sieve and the particle mass. In a few specialized cases, the sieve is stationary, but in most commercial screening applications, the particle mass flows over a sieve, wherein some type of motion is mechanically applied. The motion is intended to enhance both the flowrate and the passage of undersize particles through the sieve. When vibration is applied to a screen where there is a static bed of material present, a phenomenon called "trickle stratification" occurs, causing the particles to stratify into layers with finer particles at the bottom to coarser particles at the top. The intensity of the vibration affects the number of times a particle comes into contact with the screen surface. The more opportunities a particle has to come into contact with the screen opening, the greater the probability of passage through the screen. There are different types of motion that can be applied, depending on the design of the screening machine, and each has unique characteristics. Generally, vibratory screening machines are typically divided into six basic categories, as detailed in the following section.

Gyratory screen. The gyratory screen is a precision screener that typically has an operating speed of around 285 revolutions per minute (rpm) and a horizontal circular stroke of 2.5 in. This type of screener serves a broad range of industries and is available with multiple screen decks with a range of surface openings from 1 in. to 50 mesh.

Straight-line reciprocating screen. The straight-line reciprocating screen is a high-capacity precision screen that normally has operating parameters of 475 rpm with a 1-in. stroke, zero pitch and a slope of 6 deg. This type of screener also serves many industries, as it provides up to 800 ft^2 of deck surface with a range of surface openings from 1 in. to 40 mesh.

FIGURE 2. **Bulk solids are separated and move through gravity-separation machinery based on terminal velocity and gravity**

High-speed inclined vibrating screen. The inclined vibrating screen is a high-speed screen with a typical operating speed of 1,200 rpm with ¼-in. vertical circular stroke. This type of screener is often used in coal preparation and aggregates, with deck surfaces ranging in size from 6 in. to 10 mesh.

High-speed horizontal vibrating screen. The horizontal vibrating screen is another type of high-speed screen that typically has operating parameters of 850 rpm with a ½-in. stroke and a 45-deg attack angle. The horizontal vibrating screen is used in the same type of applications as the inclined vibrating screen. Deck surface openings range in size from 3 in. to 10 mesh.

High-frequency screen. High frequency-screens usually employ vibration that is transmitted to the screen at an operating speed of 3,000 rpm. Additionally, a burst cycle, reaching 4,500 rpm, is provided to control screen blinding. This type of screen is used for fine-mesh screening, with deck sizes ranging from 3/16 in. to 325 mesh.

Circular screen. Circular screens, sometimes referred to as sifters, are single or multi-deck screeners with diameters that range from 18–72 in.

FIGURE 3. While the automation and control techniques for gravity separators are quite advanced, a typical modern gravity separator, as shown here, has utilized the same operating principles for nearly 100 years

Deck surface openings range from ¼ in. to 325 mesh.

Specific gravity separation

While most engineers in industries that process dry materials know what a gravity separator (Figure 2) does, its work is difficult to define with precision. The statement "a separator classifies dry, free-flowing, granular mixtures by weight or bulk density or specific gravity" is accurate. But a more precise definition would add the qualification "if all the particles in the mixture are the same size and shape." With equal accuracy, the statement could be turned upside down to read, "if all the particles are the same shape and specific gravity, the separator will classify them according to size." Unfortunately, all of the particles in any given mixture are never exactly alike in size or shape. One way to more clearly understand the specific gravity theory is to understand the particle's terminal velocity (V_t), which is defined in Equation (3), in terms of mass (m), gravity (g) and density (ρ). Frontal area (A_f) is the size and coefficient of drag (C_d) relates to the shape and surface texture of a given particle.

$$V_t = \sqrt{\frac{2mg}{\rho A_f C_d}} \qquad (3)$$

The terminal velocity of particles has historically been an extremely important topic — one could look back to Galileo dropping two rocks (one heavy and one lighter) from a tower or to Newton's confirmation of the theory of gravity to arrive at the beginning of evaluations of a particle's terminal velocity. What Galileo had intended to demonstrate was that the attraction of gravity acts equally on all bodies, regardless of size or weight. This being true, they should, neglecting air resistance, accelerate at the same rate and thus travel equal distance in the same time.

Had Galileo employed in his experiment smaller weights, say rock fragments 1/4 and 1/16 in. in diameter, he would have found air resistance hard to neglect. It is this resistance in any fluid, whether liquid or gas, to motion of a solid body, that makes gravity separation possible. Figure 3 shows the clear separation of solid components in a gravity separator, as metal pellets move through the machine via gravity flow. Gravity alone, with equal intensity on all bodies regardless of size or weight, would be of no use unless there were some other resisting force, sensitive to size and weight, to balance it. And taken further to understand how a gravity separator works, the stratification upon which the separation largely depends, occurs according to the terminal velocity in air of the particles composing the mixture. Particles with higher terminal velocities are "heavies" and those with lower values are "lights."

Dry separation equipment first appeared over a century ago when the fluidized-bed separator, then called the specific gravity separator, was invented by Edwin Steele and Henry Sutton [*1*]. Constructed of wood, early gravity separators were originally developed to concentrate gold and other metallic ores without using water. By 1919, when a patent application for the technology was submitted, this new separator had found its way into many other dry materials markets, including field seeds, peanuts, peas, beans, corn, beach sands, coal, cork, chemicals and many other bulk solids.

The gravity separator (also known as fluidized-bed separator, air table or density separator) makes a highly sensitive dry separation on the basis of one of three particle characteristics: density, size or shape. When two of these characteristics are controlled within certain limits, the gravity separator is unmatched in its ability to separate a complex mixture into a continuous gradation across the range of differentiating characteristics (light to heavy, fine to coarse, or platy to granular), while permitting the isolation of many intermediate fractions between the two extremes. The ability to produce intermediate or "middling" fractions distinguishes these machines from other kinds of dry separation equipment. This property and this property alone, permits the development of high-purity concentrations without loss of efficiency in recovery. For example, when processing copper wire, a gravity separator will divide insulation materials into copper, insulation and copper-containing insulation, so the latter can be reduced further before being brought back to the gravity separator, as seen in Figure 4.

In addition to material density, the relative size and shape of each component of the mixture also bear on the efficiency of the separation. Wide variations in these material characteristics can dramatically affect the separation results. Where a wide range of particle sizes is present, screening may be required to segregate materials into manageable size ranges prior to gravity separation. Where significant variations in shape are found to be detrimental to separation efficiency, size reduction may be added to the process to reduce the range of variation. These factors become more important as the densities of the materials to be separated become closer.

In operation, the material is fed onto the narrow side of a flat porous deck, sloped in two directions and vibrated with a straight-line reciprocating motion. Low-pressure air, blown upward through the deck, fluidizes and stratifies the material according to differences in the terminal velocity of the particles. Heavy particles sink to the bottom of the stratified bed and are conveyed upward toward the high or "heavy" side by the deck's vibration. Light particles, lifted by the fluidizing air, flow downslope toward the light-end discharge. Particles with intermediate characteristics form a mixture between the light and heavy fractions and may be drawn off for retreatment. Affected by both the vibration and airflow, the material bed thins as the deck broadens toward the discharge face. Here, the material is arrayed from heaviest to lightest in a thin layer than can be precisely and easily divided into multiple fractions. Adjustable cutting fingers, positioned to make the final selection between separated fractions, direct each fraction to a separate discharge spout.

Gravity separators are generally available in two basic designs: rectangular-deck models and the more common trapezoidal-deck models. Rectangular-deck separators are recommended strictly for light-end separations where the objective is to separate a clean, light tailing from a larger amount of heavy material, like removing trash or sticks from grains or seeds. Conversely, trapezoidal-deck separators are recommended for heavy-end separations, requiring the removal of a relatively small amount of heavy material, such as removing small rocks in a material stream.

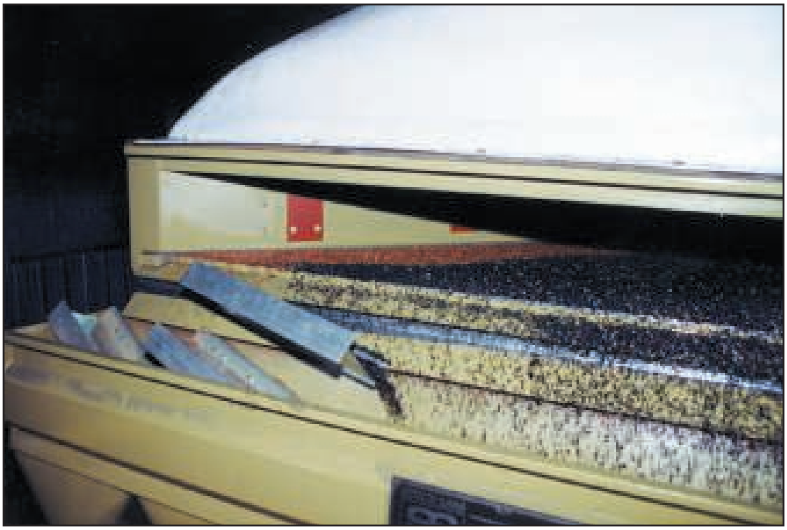

FIGURE 4. Processing a chopped power cable to recover its copper content is an example of a gravity separation where the "heavy" fraction (in this case, copper) must be isolated from the "light" fraction

Today, some manufacturers offer both the original pressure-style gravity separator and the vacuum version, which instead of blowing air up through the unit, uses a vacuum to suck the air down across the face of the deck. A pressure-style gravity separator can be tuned for a more precise air distribution or separation than the vacuum style. And while the pressure-style machine has fewer seal points that require maintenance, the vacuum style of gravity separator is more sanitary and easier to clean. The vacuum style runs considerably quieter at the operator's station and requires only one blower on dusty material.

While technology has made the controls aspect of the specific gravity separator simpler, fundamentally, the operation is the same as it was at the turn of the century. Going forward, gravity separators, as well as air classifiers and screening equipment will continue to be crucial to any industrial application that must handle dry bulk-solid materials. ■

Edited by Mary Page Bailey

References

1. A History of Innovation and Custom Engineering, www.sssdynamics.com/about/history

Acknowledgements

The authors would like to acknowledge that some of the text and photography for this article were taken from notes and documents of the archives of Triple/S Dynamics.

Authors

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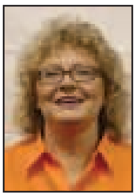
Chris Meadows is a market development specialist at Triple/S Dynamics, Inc. (Same address as above; Email: cmeadows@sssdynamics.com). Meadows has over 20 years of experience in the dry-solids processing industry.Prior to joining Triple/S Dynamics, Meadows served 17 years as vice president of sales and marketing for Progressive Industries. Meadows was educated at the University of Alabama, where he majored in marketing.



Celie A. Reid is a sales and marketing manager at Triple/S Dynamics, Inc. (Same address as above; Email: creid@sssdynamics.com). She has over 25 years experience in marketing and advertising, including beginning her career at Bozell, a full-service agency in Houston. Reid has been with Triple/S Dynamics for over ten years.

Mega columns, mega issues

With 38 years of experience, Mike Resetarits consults on distillation, absorption and extraction processes. Each month, Mike shares his first-hand experiences with *CE* readers

New distillation columns are getting much larger. The history of column sizes, and design and construction issues associated with large columns were recently addressed at the AIChE Spring Meeting (New Orleans, La.; March 30 to April 3) by Dan Summers of Sulzer Chemtech (Winterthur, Switzerland; www.sulzer.com), Bob Miller of UOP (Des Plaines, Ill.; www.uop.com) and Henry Kister of Fluor Corp. (Irving Tex., www.fluor.com). They focused on trayed, rather than packed columns. It is entirely possible that the largest-volume distillation column in the U.S. was recently commissioned — a C3 splitter with a diameter of 28 ft and a tangent-to-tangent height of 309 ft. That column included four-pass trays.

When high liquid flowrates are encountered at such large diameters, tray designers increasingly consider six- and eight-pass crossflow configurations. Many tray designers avoid odd numbers of passes. As the number of flow passes is increased, the number of column inspection manways should increase accordingly. With very long flow-paths, froth height gradients can cause vapor maldistributions and even vapor crossflow channeling. With large bubbling areas, froth stagnancies can occur. Push devices can correct such maladies, but those devices must be selected and positioned by experienced experts.

The mechanical design work associated with mega-sized trays is even more challenging. Tray parts need to fit through column manholes that are usually only 24 in. (nominal) in diameter. Those tray parts need to overlap support rings in column shells where 1% out-of-roundness can yield installation difficulties if the rings are not wide enough. Many engineers know the importance of ring and tray levelness, but with diameters as large as 50 ft, target levelness is more difficult to achieve, especially if the rings are shop-installed with the column shell in a horizontal position. Similarly, trays must not sag excessively. Miller stated that with UOP Multiple Downcomer (MD) trays, I-beams are required at diameters greater than 32 ft. Downcomers can sometimes help to support large trays.

Propylene towers are always tall. Columns designed prior to 2000 were often excessively slender and required guy wires to prevent swaying. Today's mega-sized columns are so large in diameter and shell thickness that guy wires are not needed. The weight of these towers, however, demands deep foundations. The design and fabrication of the shells are challenging even to the best of shops. Huge shells need to be shipped to the production site, then righted and positioned on the base studs. The feed and product streams of huge towers are similarly huge. Many manholes are recommended. Nozzles must be properly sized and feeds must be properly distributed, especially where a second phase is involved.

In 1990, I designed a set of trays for a propylene column that was 14 ft in diameter. Back then, that column was considered to be huge. Back then, I knew of no columns that were taller than 300 ft. These days, column heights are regularly approaching 330 ft. In the U.S., hydraulic fracturing is making ethane and propane very available. In response, very large olefin plants are being designed and constructed. Column sizes are setting records and engineers are entering uncharted areas. ■

Mike Resetarits

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Gerhard Baumann becomes managing director for **Brookfield GmbH** (Lorch, Baden-Wuerttemberg, Germany), a maker of laboratory instrumentation.

Specialty gas company **Air Products** (Lehigh Valley, Pa.) appoints *Seifi Ghasemi* chairman, president and CEO, succeeding *John McGlade*, who is retiring.

Jonathan Guy becomes president and CEO of **Waltron Bull & Roberts** (formerly Waltron LLC; Whitehouse, N.J.), a maker of water-quality instruments. Outgoing owner and CEO *John Walsh III* will serve as chairman emeritus.

NAEL Corp. (Issaquah, Wash.), a service provider to the power industry, welcomes *Thomas Bartolomei* as senior vice president and chief commercial officer.

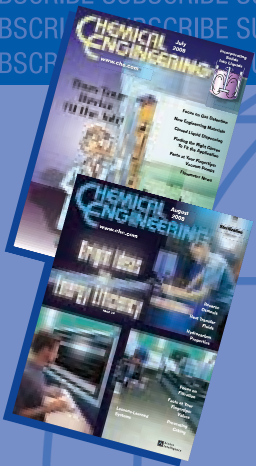
BASF SE (Ludwigshafen, Germany) appoints *Ralf Spettmann* president of the construction chemicals operating division.

Lawrence Quinn becomes CEO, water purification, for **Severn Trent Services** (Fort Washington, Pa.), a provider of water- and wastewater-treatment solutions.

ValvTechnologies (Houston), a maker of valves for severe service, promotes *Todd Blackburn* to director, global quality management.

Maelys Castella becomes CFO of chemical company **AkzoNobel** (Amsterdam, the Netherlands). ■

Suzanne Shelley



BUSINESS NEWS

PLANT WATCH

ExxonMobil invests in new delayed coker unit at Belgium refinery

July 7, 2014 — An affiliate of ExxonMobil (Irving, Tex., www.exxonmobil.com), Esso Belgium, a division of ExxonMobil Petroleum & Chemical B.V.B.A., plans to install a new delayed coker unit at its Antwerp, Belgium petroleum refinery. The investment for this refinery upgrade totals more than $2 billion.

Five-member consortium plans new MDI plant in Shanghai

July 1, 2014 — BASF SE (Ludwigshafen, Germany; www.basf.com), Huntsman Corp., Shanghai Hua Yi (Group) Co., Shanghai Chlor-Alkali Chemical Co. and Sinopec Group Assets Management Corp. formed a consotrium to construct a new plant at Shanghai Lianheng Isocyanate Co. in Caojing, China. The facility will have production capacity of 240,000 metric tons per year (m.t./yr) of crude MDI (diphenylmethane diisocyanate). With the new plant, the total MDI capacity at this site will double to 480,000 m.t./yr. The facility is expected to start up in 2017.

Kuraray to expand U.S. facilities for polyvinyl alcohol production

June 27, 2014 — Kuraray Co. (Tokyo, Japan; www.kuraray.co.jp) will expand its production facilities for polyvinyl alcohol (PVA) in the U.S. at its wholly owned subsidiary Mono-Sol, LLC. Kuraray will establish a new factory in Portage, Ind. for PVA film production. The first phase of construction requires an investment of around $25 million, with operations targeted for startup in January 2016.

Topsøe to establish catalyst manufacturing facility in Brazil

June 26, 2014 — Haldor Topsøe A/S (Lyngby, Denmark; www.topsoe.com) is currently in the process of establishing a production facility in Brazil. The facility will focus on manufacturing catalysts that remove nitrogen oxides, particulate matter and hydrocarbons from the engine exhaust of diesel vehicles.

Foster Wheeler awarded contract for steam-reformer heater in Russia

June 25, 2014 — A subsidiary of Foster Wheeler AG (Zug, Switzerland; www.fwc.com) has been awarded a contract by Glencore Oil Projects AG for a steam-reformer heater for hydrogen production for the Orsknefteorgsyntez Refinery at Orsk, Russia. Foster Wheeler's scope of work is scheduled to be completed in the second quarter of 2015.

Oxea completes specialty esters plant in Nanjing

June 23, 2014 — Oxea GmbH (Oberhausen, Germany; www.oxea-chemicals.com) says that its specialty esters plant in Nanjing, China, is now mechanically complete. The new plant, Oxea's first production site in Asia, is currently in the commissioning and startup phase. It will boost Oxea's global production capacity for specialty esters by 40%.

Asahi Kasei will construct manufacturing plant for new optical polymer

June 19, 2014 — Asahi Kasei Chemicals Corp. (Tokyo, Japan; www.asahi-kasei.co.jp) has developed as a new optical polymer called AZP. Manufacturing facilities for AZP will be constructed at the company's plant in Chiba, Japan, with startup scheduled for early 2015. Anticipated applications for AZP are in high-performance displays and various optical components.

Versalis/Novamont joint venture Matrìca inaugurates biorefinery in Italy

June 17, 2014 —Matrìca S.p.A (Porto Torres, Italy; www.matrica.it), the 50/50 joint venture (JV) between Versalis and Novamont, has inaugurated its first biorefinery complex, located in Porto Torres, Italy. Consisting of three plants, the complex will convert vegetable oils into monomers and intermediates for a variety of industries, producing a total of approximately 70,000 m.t./yr of bio-products.

Chevron Phillips starts up new on-purpose hexene production plant

June 13, 2014 — Chevron Phillips Chemical Co. LP (The Woodlands, Tex.; www.cpchem.com) has announced the successful commissioning and startup of what is said to be the world's largest on-purpose 1-hexene plant. Located at the Cedar Bayou Chemical Complex in Baytown, Tex., the 1-hexene unit is capable of producing 250,000 m.t./yr.

MERGERS AND ACQUISITIONS

Kemira to acquire paper chemicals business from AkzoNobel

July 8, 2014 — Kemira Oyj (Helsinki, Finland; www.kemira.com) has reached a preliminary agreement to acquire AkzoNobel's global paper chemicals business, valued at €153 million. The closing of the transaction is expected in the first quarter of 2015.

Washington Penn to purchase assets of ExxonMobil's PP compounding business

July 8, 2014 — Washington Penn Plastic Co. has concluded an agreement with Exxon-Mobil Chemical Co. (EMC; Houston; www.exxonmobilchemical.com) to purchase and license assets of EMC's North American specialty compounded polypropylene (PP) products business, following EMC's decision to cease production of those products in North America.

GE enhances wastewater-treatment portfolio with acquisition of Monsal

July 7, 2014 — GE Power & Water (Schenectady, N.Y.; www.gepower.com) has agreed to acquire Monsal (Mansfield, U.K.; www.monsal.com), a private company specializing in water, waste, anaerobic digestion and integrated biogas-to-energy technologies. This acquisition will enhance GE's wastewater-treatment product offerings.

Ineos to acquire BASF's share in Styrolution for €1.1 billion

June 30, 2014 — Ineos (Rolle, Switzerland, www.ineos.com) will acquire BASF's 50% share in Styrolution, a JV between the companies. The purchase price to be paid by Ineos is €1.1 billion. Completion of the deal is expected in the fourth quarter of 2014.

Solvay and Ineos to create chlorovinyls producer JV, called Inovyn

June 26, 2014 — Solvay S.A. (Brussels, Belgium; www.solvay.com) and Ineos will create a JV for chlorovinyls, to be named Inovyn and headquartered in London, U.K. The JV is expected to be effective by year-end 2014.

H.B. Fuller to acquire Tonsan Adhesive for $230 million

June 26, 2014 — H.B. Fuller Co. (St. Paul, Minn.; www.hbfuller.com) has signed an agreement to purchase Tonsan Adhesive, Inc. for $230 million. Tonsan, with current annual revenue of around $100 million, is said to be the largest independent engineering-adhesives provider in China.

Yara to acquire Borealis' stake in French urea plant

June 17, 2014 —Yara International ASA (Oslo, Norway; www.yara.com) will acquire Borealis' 52.15% ownership in a urea plant in Le Havre, France. With this purchase, Yara gains access to an additional 160,000 m.t/yr of urea production capacity. ■

Mary Page Bailey

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Pipes, valves & fittings	876.2	874.5	863.4
Process instruments	410.9	408.8	410.6
Pumps & compressors	938.6	937.3	919.3
Electrical equipment	515.3	514.4	513.1
Structural supports & misc	767.4	767.3	741.7
Construction labor	320.8	320.4	319.7
Buildings	543.2	542.3	534.0
Engineering & supervision	321.5	322.4	325.5

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2008 = 575.4
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2010 = 550.8
2011 = 585.7
2012 = 584.6
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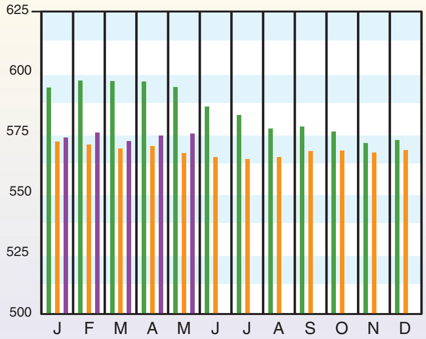
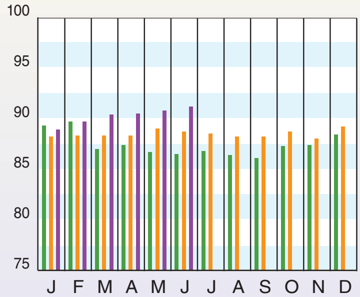


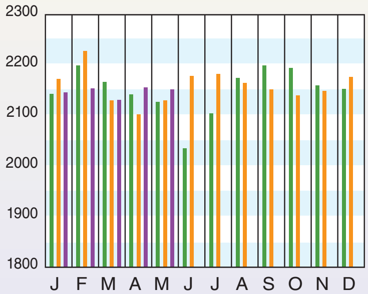
CURRENT BUSINESS INDICATORS*

	LATEST			PREVIOUS						YEAR AGO		
CPI output index (2007 = 100)	Jun. '14	=	91.2	May '14	=	90.8	Apr. '14	=	90.5	Jun. '13	=	88.7
CPI value of output, $ billions	May '14	=	2,152.5	Apr. '14	=	2,156.4	Mar. '14	=	2,131.9	May '13	=	2,130.6
CPI operating rate, %	Jun. '14	=	76.8	May '14	=	76.6	Apr. '14	=	76.4	Jun. '13	=	75.6
Producer prices, industrial chemicals (1982 = 100)	Jun. '14	=	288.9	May '14	=	288.4	Apr. '14	=	295.7	Jun. '13	=	303.1
Industrial Production in Manufacturing (2007 = 100)	Jun. '14	=	99.7	May '14	=	99.6	Apr. '14	=	99.1	Jun. '13	=	96.4
Hourly earnings index, chemical & allied products (1992 = 100)	Jun. '14	=	158.4	May '14	=	155.4	Apr. '14	=	157.1	Jun. '13	=	156.0
Productivity index, chemicals & allied products (1992 = 100)	Jun. '14	=	108.3	May '14	=	107.8	Apr. '14	=	108.6	Jun. '13	=	106.2

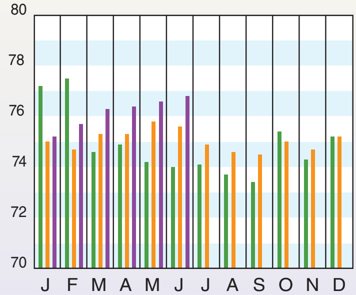
CPI OUTPUT INDEX (2007 = 100)



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), a leading economic indicator created by the American Chemistry Council (ACC; Washington, D.C.; www.americanchemistry.com), continued its upward growth in the month of June, showing a 0.5% gain from the May CAB value. Though the pace of growth has slowed significantly, gains in June have brought the CAB up a solid 4.3% over this time last year.

"Overall, we are seeing signs of continued growth in the U.S. economy, and trends in construction-related chemistry show a market which has not yet reached its full potential," said Kevin Swift, chief economist at ACC. "However, unrest in Iraq is already affecting chemical equity prices, and the potential for an energy price shock is worrying," he added.

In one of its Weekly Chemistry and Economic Reports from July, the ACC said the current number of chemical industry projects designed to take advantage of the growth in shale gas production has grown to 188. The 188 total projects represent a cumulative capital investment of $116.9 billion in the U.S., of which 62% is foreign direct investment. ACC maintains and updates a list of shale-gas-related projects. In March of last year, the total announced investment was $71.7 billion for 97 projects.

The ACC report mentioned the fact that the International Energy Agency (IEA; Paris; www.iea.org) recognized the U.S. as the leading global producer of natural gas liquids.

In another Weekly Chemistry and Economic Report from July, the ACC noted that its index for chemical company equity prices was flat in June. Since the beginning of the year, the ACC index for chemical stocks is up 8.6%. ❑

CURRENT TRENDS

The preliminary value for the May *CE* Plant Cost Index (CEPCI; top; the most recent available) rose 0.1% from the final April value, after a slightly larger rise the previous month. All subcategories of the index saw slight increases, except for Engineering & Supervision, which declined slightly. The preliminary overall PCI value for May 2014 stands at 1.4% higher than the value from May of last year. Meanwhile, updated values for the Current Business Indicators (CBI) from IHS Global Insight (middle) saw a small increase in the CPI Output Index and a small decrease in the the CPI Value of Output compared to the previous month's values. The Productivity Index for chemicals moved slightly higher. ❑