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June 2013

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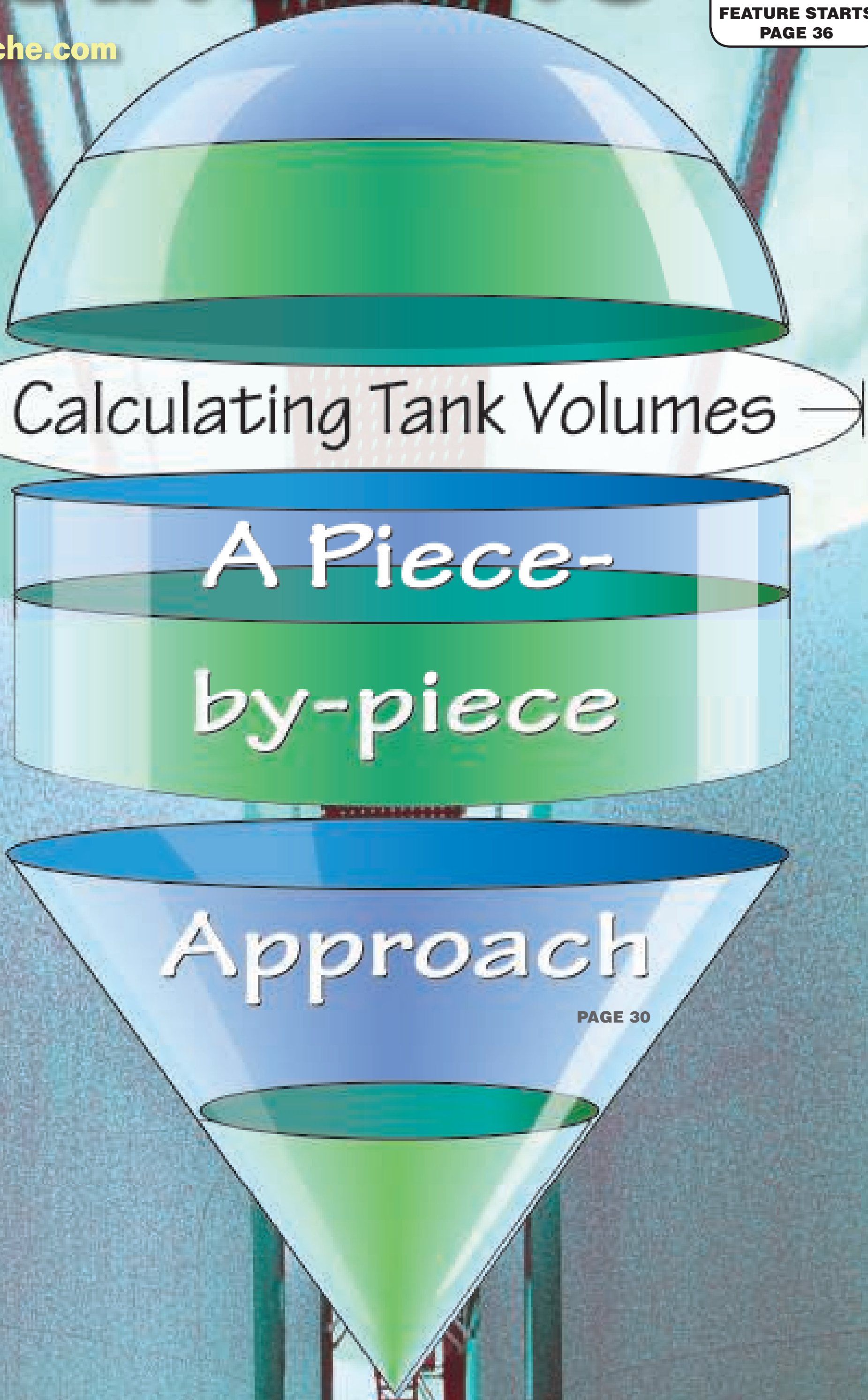
Automation Standards

TWO-PART FEATURE STARTS PAGE 36



Controlling Air Pollutants

Sonochemistry

Focus on Explosion Protection

Vapor Depressurization

Process Development

Dry Gas Seals

Facts at Your Fingertips: Solids Conveying

Access Intelligence

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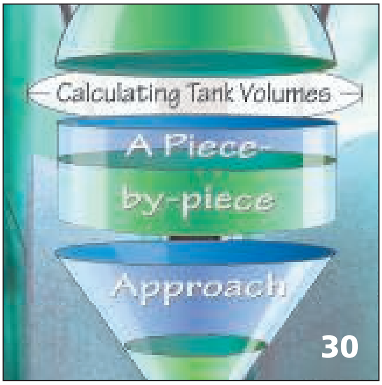

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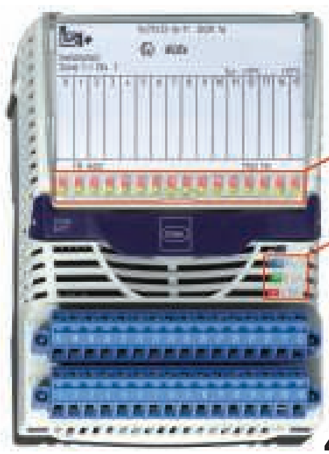

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COMING IN JULY

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Cover: David Whitcher

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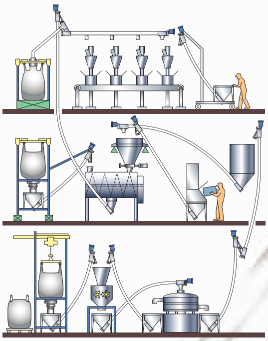

5 Convey at multiple locations
Available mounted on mobile bases with casters, Flexicon conveyors with hoppers, dust collectors and other accessories can operate at multiple locations, eliminating the need for dedicated conveyors.

6 Save on sanitary construction
Other conveyors can command high premiums for USDA, 3-A dairy and pharmaceutical models, but Flexicon conveyors can meet sanitary requirements at comparatively low cost.

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Editor's Page

The pending water shortage

There is an emerging crisis brewing for the chemical processing industries (CPI) in many regions of the world. Those regions include China, the world's manufacturing powerhouse; swaths of the U.S., including large parts of its South; and chunks of Europe.

For once, the crisis has nothing to do with energy costs. The emergence of cheap shale gas in the U.S., and the identification of exploitable basins in other places (even though adapting hydraulic fracturing technology for these new finds will be difficult), is painting a much brighter picture of future energy availability than we have witnessed for decades.

The crisis this time is fresh water availability. Already, in many regions, there are regular periods of very tight water supply, and current weather patterns (whether or not you believe that they are caused by man-made global warming) are exacerbating the problem. Some technology trends, including biotechnology processes that are touted as being environmentally friendly, will also increase the pressure on water availability.

Global chemical company, DSM (Heerlen, the Netherlands; www.dsm.com), estimates that only 0.02% of the world's total water is available for industrial and domestic use. Only 3% of the Earth's total water is fresh water, and 2% of that is locked up in the polar ice caps and glaciers. Only 0.2% of the world's water is available for consumption. The industrial and domestic share is about 0.02%, with the rest going to agriculture.

Now imagine a world with 50% more people in the next 40 years, all needing abundant supplies of fresh water for nourishment and sanitation. How will industry continue its growth on a resource-limited planet?

There are three likely outcomes of this emerging crisis: rising costs for water; competition for water rights between industry and municipal governments and other claimants; and a drive within the CPI to establish a better understanding of water consumption and how to manage and reduce it.

At this point, most CPI plants do not have a clear view of their water consumption. Try to calculate it, and the math is not straightforward.

For the CPI to consume water responsibly, and sustainably, there are several steps that need to be taken. Every plant should, and ultimately will have to, estimate its own water footprint and know how much surface or ground water, in particular, it is consuming. CPI plants need to understand how their water footprints impact the local community, both in terms of managing water scarcity and in terms of reducing pollution from wastewater.

CPI plants also need to set aggressive targets for reducing their water footprints. This should not be thought of just as "doing good," but as risk management. Pose the question in terms of the right outcome for the planet, and most CPI executives will balk at reducing their water footprint. Pose it in terms of managing the risk of restricted access to water, and you will get a lively, engaged conversation, and rather quickly a business plan that involves reducing fresh water consumption.

In its water assessments, DSM has gone a lot further than just estimating a water footprint, but has also calculated its "fair share" of water availability, and vowed to have no adverse impact on the "availability and quality of groundwater or surface water in the areas where we operate."

How many in the CPI are ready to make a similar commitment? If this is not done voluntarily, it will probably happen because of public opinion or legislation, as the water crisis deepens. Get ready, water will be a big part of your professional life in the years ahead. And, if you do not start to take account of water issues, no amount of cheap shale gas will make you successful. ■

John Pearson, CEO, Chemical Industry Roundtables

Letters

Seeking input on distillation education

Right now, distillation engineers are extremely busy — globally, and especially in the U.S. The AIChE Distillation Symposium (May, San Antonio, Tex.) that was organized by Henry Kister and Mike Pritchett had an amazing number of presentations and attendees.

FRI is the world's premier distillation research facility. FRI engineers who teach a separations course at Oklahoma State University had an idea: To create a training module entitled "Distillation" for university chemical engineering courses. That module would include PowerPoint presentations, videos from FRI's experimental unit and an easy-to-use computer program.

The PowerPoint presentations would include the following: boiling points including pressure effects, relative volatilities, *y*-versus-*x* vapor-liquid equilibrium (VLE) graphs, McCabe-Thiele constructions, VLE thermodynamic models, process simulation programs, the reflux concept, equilibrium stages, staging-versus-reflux graphs, reboilers and more. FRI engineers would continuously keep the presentations up-to-date.

The videos would show the FRI test columns and would include descriptions of the following: boiler, cooling tower, storage tanks, pumps, valves, thermocouples and more. The videos would also include footage through the FRI column windows — trays and packings in operation, including at the flood points.

The computer program, which is presently called "DRP Lite," would allow future engineers to size (roughly) trayed and packed (random and structured) columns, using popular literature correlations. Capacities, pressure drops and efficiencies would be calculated.

The proposed FRI training module would not be designed to replace textbooks or the presentations that typically accompany textbooks. Instead, the training module would augment those materials by providing real-world photographs and videos. The training module would include hot-off-the-presses data, information and technologies. Homework problems would still come from the textbooks. The training module would assume that a total of eight 1.5-h lectures would be devoted in a separations class to distillation. The target audience would be college juniors, seniors and graduate students in chemical engineering programs.

FRI engineers have not yet initiated work on the training module. We await input from *Chemical Engineering* readers, including students, recent graduates and instructors. Would you use such a module? Any ideas for such a module? Please provide a paragraph or two to resetarits@fri.org.

Mike Resetarits
Fractionation Research, Inc. (FRI)

Bringing mobility to the plant

Just started going through the April issue of *CE* this weekend. Excellent segment on the use of mobile technology. Very timely and well done.

Bill Huitt
W. M. Huitt Co.

Circle 13 on p. 56 or go to adlinks.che.com/45773-13

Calendar

NORTH AMERICA

Risk Management of Corrodible Systems. National Assn. of Corrosion Engineers (Houston). Phone: 281-228-6200; Web: event.nace.org
Orlando, Fla. **June 18–20**

Valve World Americas Expo & Conference. Messe Düsseldorf North America (Chicago, Ill.). Phone: 312-781-5185; Web: mdna.com
Houston **June 25–26**

Elastomer Technology & Seal Design for the Oil & Gas Industry. Precision Polymer Engineering (Blackburn, U.K.). Phone: +44-1254-295400 Web: idexcorp.com
Houston **June 27**

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

Introduction to Foundation Fieldbus. Fieldbus Foundation (Austin, Tex.). Phone: 512-794-8890.; Web: fieldbus.org
Austin, Tex. **Aug. 20**

Advanced Principles of Foundation Fieldbus. Fieldbus Foundation (Austin, Tex.). Phone: 512-794-8890; Web: fieldbus.org
Austin, Tex. **Aug. 21–23**

American Chemical Soc. 246th National Meeting and Exposition. American Chemical Soc. (Washington, D.C.). Phone: 202-872-4600; Web: acs.org
Indianapolis, Ind. **Sept. 8–12**

4th Annual ChemInnovations Conference & Expo. TradeFair Group, an Access Intelligence LLC Co. (Houston). Phone: 713-343-1891; Web: cpievent.com
Galveston, Tex. **Sept. 25–26**

42nd Turbomachinery and 29th International Pump Users' Symposia. Texas A&M University (College Station, Tex.). Phone: 979-845-7417; Web: turbolab.tamu.edu
Houston **Sept. 30–Oct. 3**

Elastomer Technology & Seal Design for Oil & Gas. Precision Polymer Engineering (Blackburn, U.K.). Phone: +44-1254-295400; Web: idexcorp.com
Houston **Oct. 8**

EUROPE

Introduction to Foundation Fieldbus. Industry Source (Mesa, Ariz.). Phone: 480-775-6020; Web: fieldbus.org
Frankfurt am Main, Germany **June 18**

Advanced Principles of Foundation Fieldbus. Industry Source (Mesa, Ariz.). Phone: 480-775-6020; Web: fieldbus.org
Frankfurt am Main, Germany **June 19–21**

5th Symposium on Continuous Flow Reactor Technology. AIC ASTI Incentives & Congressi s.r.l. (Pisa, Italy). Phone: +050-598808; Web: aicgroup.it
Pisa, Italy **Sept. 11–12**

Elastomer Technology & Seal Design for Oil & Gas. Precision Polymer Engineering (Blackburn, U.K.). Phone: +44-1254-295400; Web: idexcorp.com
Duisberg, Germany **Oct. 22**

Elastomer Technology & Seal Design for Semiconductors. Precision Polymer Engineering (Blackburn, U.K.). Phone: +44-1254-295400; Web: idexcorp.com
Dresden, Germany **Oct. 24**

Elastomer Technology & Seal Design for Critical Sealing Applications. Precision Polymer Engineering (Blackburn, U.K.). Phone: +44-1254-295400; Web: idexcorp.com
Blackburn, U.K. **Nov. 6–7**

Introduction to Foundation Fieldbus. Fieldbus Foundation (Austin, Tex.). Phone: 512-794-8890; Web: fieldbus.org
Frankfurt am Main, Germany **Nov. 12**

Advanced Principles of Foundation Fieldbus. Fieldbus Foundation (Austin, Tex.). Phone: 512-794-8890; Web: fieldbus.org
Frankfurt am Main, Germany **Nov. 13–15**

ASIA & ELSEWHERE

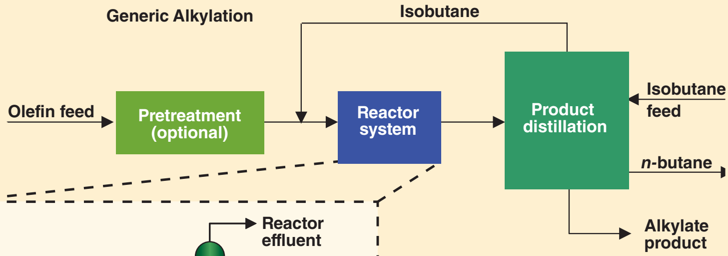
26th Interphex Japan. Reed Exhibitions (Tokyo, Japan). Phone: +81-3-3349-8518; Web: interphex.jp
Tokyo, Japan **July 10–12**

In-Cosmetics Asia. Reed Exhibitions (Norwalk, Conn.). Phone: +44-20-8271-2122; Web: in-cosmeticsasia.com
Bangkok, Thailand **Oct. 29–31** ■

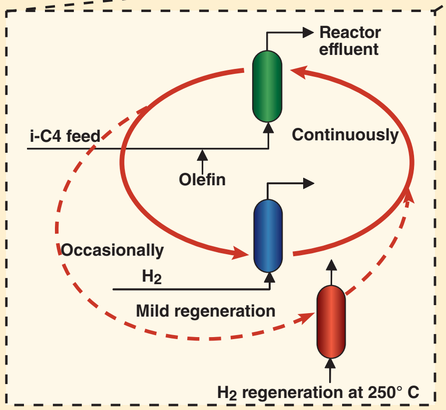
Suzanne Shelley

CHEMENTATOR

Edited by Gerald Ondrey June 2013



A solid-acid-catalyst alkylation process will be commercialized . . .



What is said to be the world's first commercial alkylation plant to use a solid acid catalyst is scheduled for startup early next year by Shandong Wonfull Petrochemical Group Co. (Zibo, China). The plant, which will produce 100,000 ton/yr of alkylate, will use a process called AlkyClean, developed by CB&I's Technology Group (The Woodlands, Tex.; www.cbi.com), Albemarle Corp. (Orangeburg, S.C.; www.albemarle.com) and Neste Oil (Espoo, Finland; www.nesteoil.com).

AlkyClean (flowsheet) represents a breakthrough in alklylation technology in that it avoids the environmental hazards of sulfuric acid and hydrofluoric acid, the two catalysts traditionally used for alkylation. Instead, the process employs a fixed bed of a zeolite-based catalyst with noble metal function for the reaction, in which light olefins (C3–C5) are reacted with isobutane to obtain motor fuel alkylate (mostly C8 material). The octane rating of the alkylate is 94–96 RON, similar to that produced by the liquid-acid processes, says Jo Portela, CB&I's senior vice president for refining. The catalyst was developed by Albemarle.

The capital cost is about 15% below that of an H_2SO_4 plant and similar to that of an HF plant, says Portela. However, he stresses that "the key driver is the elimination of liquid acid catalysts and the costs of maintenance, the mitigation of hazards, and acid disposal. AlkyClean is a very simple, fixed-bed process and uses carbon steel throughout the plant," he says. Also, he notes that the reaction takes place at 50–90°C, thereby avoiding the refrigeration costs of the H_2SO_4 and HF method, which operates at 4–10°C.

AlkyClean works with at least three reactors in parallel (diagram). Two are online together, each cycling every 1–3 h between alkylation and mild catalyst regeneration. The third, a standby unit, goes online every few weeks, when one of the producing reactors goes offline for high-temperature regeneration at 250°C.

. . . and an improved H_2SO_4 alkylation process gains acceptance

Meanwhile, an improved H_2SO_4 process developed by CB&I (see previous item) has now been licensed to three companies, all in China. The first licensee was Ningbo Haiyue New Material Co. Ltd., which is building a 600,000-m.t./yr plant near Ningbo City, Zhejiang Province (*CE*, December 2011, p. 11). The other two plants, each of 200,000 m.t./yr, are being built by undisclosed companies in Shandong and Guangxi provinces, says Jo Portela, of CB&I. All are scheduled to start up this year.

The main advantages of the low-temperature CDAlky process over conventional H_2SO_4 alkylation are that it uses 50% less acid and the octane rating of the alkylate is 97–98 RON, versus 94–96 RON. Both benefits are obtained by contacting the reaction components in a packed column, rather than by mechanical mixing with impellers. Portela explains that the column makes for more efficient mixing and allows the reaction to take place at about –4°C, which improves the selectivity and raises the octane rating. Conventional H_2SO_4 alkylation is limited to 4–10°C because the acid becomes very viscous at low temperatures, he says. Another problem, he adds, is that the impellers create an emulsion with small acid droplets, so the alkylate has to be given a caustic wash before going to the fractionation section of the plant.

Portela says while both the CDAlky and AlkyClean processes are environmentally friendly, CDAlkyl is designed for companies that want a higher-octane alkylate, while the appeal of AlkyClean is that it completely eliminated the need to deal with liquid acid.

Ceramic paper

A paper-like material made from vanadium-pentoxide ceramic that is as hard as copper and can be folded or rolled up has been produced by scientists at Stuttgart University (www.uni-stuttgart.de), the Max-Planck Institute (MPI) for Intelligent Systems (www.is.mpg.de) and the MPI for Solid State Research (all Stuttgart, Germany; www.fkf.mpg.de). The ceramic paper consists of conductive nanofibers of V_2O_5 assembled into a structure resembling mother-of-pearl. Besides being hard, strong and pliable, the paper has a high conductivity along its plane, and low out-of-plane conductivity. Such properties may find applications in batteries, flat and flexible gas sensors and actuators in artificial limbs.

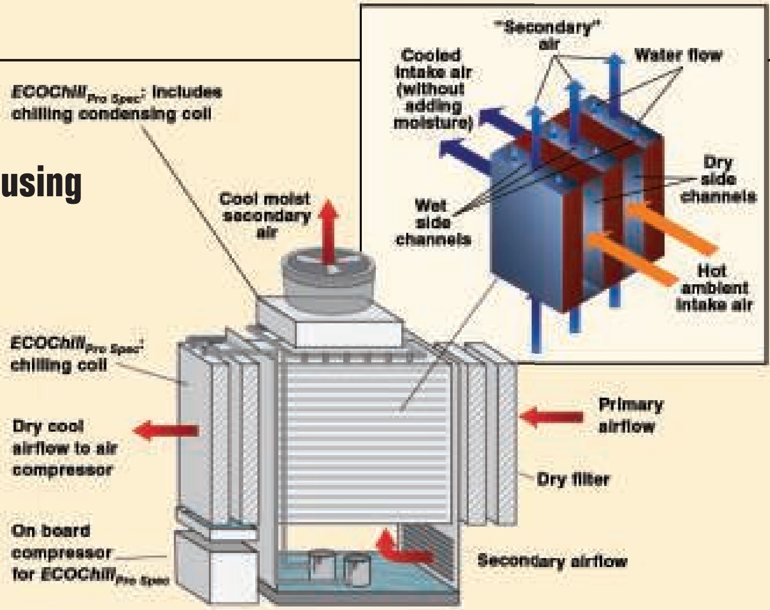
To make the paper, nanofibers of V_2O_5 are suspended in water on a substrate and the water is allowed to slowly evaporate at room temperature. The film is then heated for a few hours at 40°C, and the humidity is slowly reduced. This slow process allows the fibers to assemble themselves into a parallel pattern. Finally, the film is annealed at 100 and 150°C to make a transparent, orange paper of between 0.5- and 2.5-μm thickness (depending on the amount of nanofibers used).

Detecting asbestos

The first portable, realtime airborne asbestos detector has been developed and tested by researchers from the University of Hertfordshire's Center for Atmospheric and Instrumentation

(*Continues on p. 12*)

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



This process delivers chilled air using a fraction of the power required

The temperature and moisture level of the air being drawn into the front end of ammonia, nitrogen, nitric acid or other plant air compressors directly impacts the yield from the process, and chilling is a way to debottleneck air production in such plants. Most methods traditionally used to increase air production in the past involved process modifications, such as adding a parallel compressor or installing a larger compressor or compressor driver. Another alternative is chilling air to the intake of the existing air compressor. Although this approach has been implemented previously, the capital and operating costs have often limited the benefits.

To make this option more economical, a patented, two-stage hybrid process for supplying chilled air to chemical production processes has recently been commercialized by Everest Sciences Corp. (Tulsa, Okla.; www.ecochill.com). By combining indirect evaporative-heat extraction with a small amount of supplemental refrigeration, this hybrid technology — tradenamed ECOChill$_{\text{Pro Spec}}$ — can reduce the overall power to operate by as much as 30–70%, compared to conventional refrigeration techniques, says Marcus Bastianen, director of Sales and Marketing. In addition, the capital costs are substantially reduced because the hybrid system requires smaller chilling coils, condensing coils, compressors, evaporators and other ancillary chilling components, he adds.

The ECOChill$_{\text{Pro Spec}}$ system (diagram) uses two individual flow paths — process air and secondary air — and two stages of heat rejection to achieve the desired chilling goals, explains Bastianen. Process air is drawn through the dry-side channels of a proprietary, indirect-evaporative, cross-flow heat exchanger (IEHex), while ambient air is drawn through the secondary air flowpath on the wet-side channels of the IEHex. The secondary airflow is used for both extracting heat from the primary air and for condensing of the supplemental refrigeration unit. Because the IEHex extracts a significant amount of heat from the ambient air prior to entering the second stage of the chilling process, substantially less heat rejection is required by the supplementary chilling system compared to that of a conventional chiller, which must do all the heat rejection, says Bastianen. "The IEHex section requires virtually no power to operate and less duty is placed on the second stage supplementary chilling unit."

ECOChill was first commercialized in 2010 for applications in the oil-and-gas sector. The following year, the technology was further developed for applications in the chemical process industries (CPI), with the first commercial unit applied at PCS Nitrogen (Trinidad), which has been operating successfully since it started up in early 2012. Since then, several systems have been installed in the U.S. for N_2 and HNO_3 plants.

Acid recovery makes rutile production more economical

A demonstration plant in Newcastle, New South Wales, Australia, will produce hydrochloric acid and iron pellets from the iron-chloride leach liquor generated by the production of synthetic rutile, the common mineral form of titanium dioxide. The plant will utilize a process called EARS (enhanced acid-regeneration system) developed by Austpac Resources NL (Sydney, Australia; www.austpacresources.com). At full capacity the plant will produce 18,000 ton/yr of iron (as pellets or briquettes) and 18,000 ton/yr of acid (25 vol.% HCl). Austpac plans to start commissioning the plant during the third quarter of 2013 and start production in the fourth quarter.

EARS was developed to improve the economics of Austpac's enhanced roasting and magnetic separation (ERMS) process. EMRS is a controlled roasting process that makes the ilmenite component of the concentrate

(*Continues on p. 14*)

(*Continued from p. 11*)

Research (www.herts.ac.uk). The instrument is able to distinguish asbestos from other less dangerous fibers (such as mineral wool, gypsum and glass) by exploiting unique magnetic properties of asbestos, explains team member professor Paul Kaye.

The detector uses laser light scattering to detect the fibers. By analyzing the scattering pattern before and after a magnetic field is applied, the device is able to selectively identify asbestos fibers, which orient themselves along the direction of the magnetic field.

Together with colleagues in the U.K. and Spain, prototype units have been developed and are undergoing field testing at various asbestos-removal-operation locations. The first commercial production units are estimated to be available in 12–18 months. The method was developed as part of the FP7 project, "Alert," with funding from the European Commission.

Renewable BDO

BASF SE (Ludwigshafen, Germany; www.basf.com) plans to begin production of 1,4-butanediol based on renewable feedstock (renewable BDO) using the patented process of Genomatica (San Diego, Calif.; www.genomatica.com). The one-step fermentation process

(*Continues on p. 14*)

Continuous production of transparent sheets of cellulose nanofibers . . .

Oji Holdings Corp. (OJI; www.ojiholdings.co.jp) and Mitsubishi Chemical Corp. (MCC; both Tokyo, Japan; www.m-kagaku.co.jp) have developed a continuous process for producing transparent sheets made from ultra-thin, wood-based cellulose nanofibers (CNF). Both OJI's paper-making technology and MCC's chemical treatment technology contributed to this achievement. Purpose-built equipment has been installed at OJI's Shinonome Research Center (a $100,000 investment), and shipping of test samples has begun. The two companies anticipate commercial applications by 2016.

Thin (4-nm dia.) CNFs made from pulp have a low thermal-expansion coefficient (similar to that of glass fiber), but a higher elastic modulus than that of glass fiber. These properties could enable future applications in filtration, adsorption and catalyst supports, as well as materials for electronic, construction, transportation and medical components.

The companies have developed the technology for the continuous production of transparent, foldable, lightweight sheets from the CNFs. Ultrafine porous sheets have been made with pore sizes of 8 to 46 nm (1/100th to 1/500th that of copy paper); planar densities of 8–85 g/m^2; and specific surface areas of 39 to 148 m^2 (40–150 times larger than copy paper).

. . . a pilot plant for making CNFs . . .

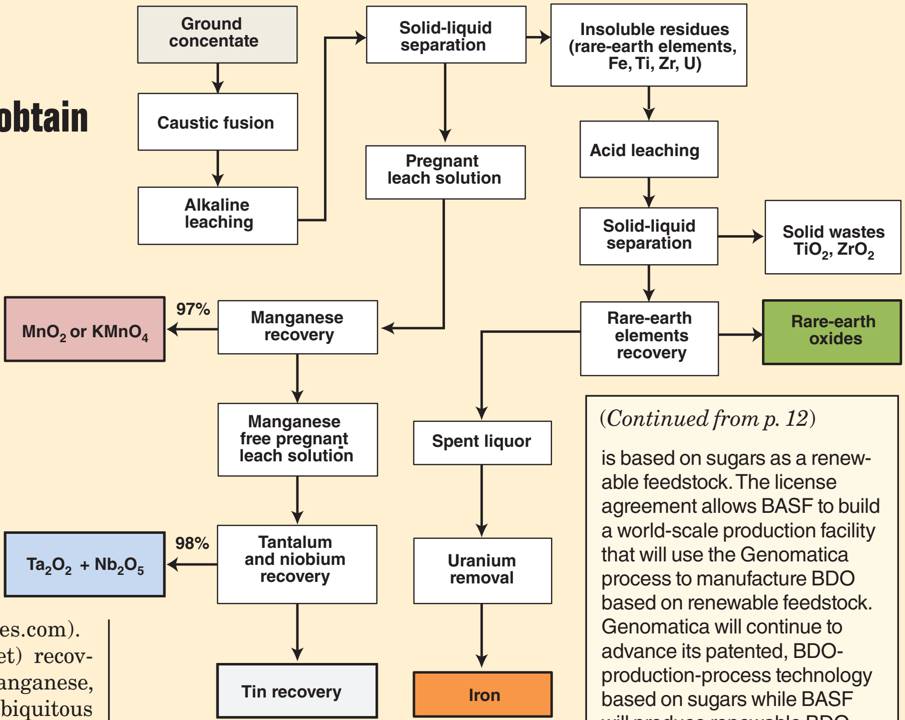
Meanwhile, Seiko PMC Corp. (Tokyo; www.seikopmc.co.jp) has installed a pilot plant for the production of CNFs at its Ryugasaki Factory, and will begin shipping samples next spring with the aim of commercial activities in 2015. In collaboration with professor Hiroyuki Yano, Kyoto University — the leader of an NEDO project "Research and Development of Nanodevices for Practical Utilization of Nanotechnology" — Seiko PMC has enhanced the compatibility of CNFs with resins for making homogeneous dispersions. The collaborators expect applications of the CNFs in automotive and electronic devices that require high-strength and lightweight materials with dimensional stability at high temperatures. With support from the Japanese Ministry of Economy, Trade and Industry, a facility for mass production is being designed. Startup is planned for next spring.

. . . and a production plant for CNFs

Nippon Paper Industries Co. (Nippon Paper; Tokyo; www.nipponpapergroup.com) is constructing a verification plant for the production of CNFs at the Chemical Div. of its Iwakuni Mill. Scheduled to start up in October, the facility will have a production capacity of 300 ton/yr or more. Working under the NEDO program mentioned above, the company has developed a chemical pretreatment process for disintegrating pulp. Last April, Nippon Paper also established a CNF Business Promotion Office within its R&D Div. to develop the CNF business using pulp as materials. The new organization aims to commercialize the CNF business at an early stage by establishing CNF mass-production technology and promoting application development.

A safer, cleaner way to obtain tantalum and niobium

Tantalum and niobium, which are often found in complex ores, are essentially chemically inert metals whose recovery involves some harsh measures: typically dissolution of the metals concentrate in a mixture of concentrated hydrofluoric and sulfuric acids, followed by solvent extraction with methyl-*iso*-butyl-ketone dissolved in kerosene. A process that is said to be safer and "greener" has been developed and patented by Electrochem Technologies & Materials Inc. (Montreal, Canada; www.electrochem-technologies.com).



Electrochem's process (flowsheet) recovers tantalum and niobium, plus manganese, rare-earth metals, tin and iron — ubiquitous elements found in Ta and Nb ores. Ground concentrate is digested in a molten potassium hydroxide, between 400 and 800°C. The melt resides for less than 1 h in a batch furnace or a rotary kiln to dissolve essentially all the tantalum and niobium, along with manganese and tin. The melt is then solidified and leached by an aqueous solution of KOH to extract Ta, Nb, Mn and Sn from the now-solidified melt. Undissolved solids, including Fe, Ti, Zr, thorium, uranium and rare-earth metals, are filtered out and the metals may be recovered by acid leaching and precipitation.

Mn is obtained from the leach solution either as manganese dioxide or potassium permanganate via a continuous electrochemical process. Next, a saturated aqueous solution of sodium sulfate or chloride is added, then the pH is adjusted to 6–7 (by adding H_2SO_4 or HCl) for selective precipitation of sodium niobate and tantalate. The metals are subsequently acid-leached to produce tantalum and niobium oxides. Finally, tin may be precipitated as tin oxide.

Francois Cardarelli, president of Electrochem, says the process has been tested at a prototype scale and has recovered 98–99% of an ore's content of Ta and Nb. Preliminary cost and benefits analyses indicate that tantalum oxide could be produced for one-third the operating cost of conventional processing, he says. Cardarelli says the initial focus is on tantalum because the daily tonnage is much smaller (hence scaleup is easier) and its value is two or three times that of niobium.

ACID RECOVERY (*Continued from p. 12*)

magnetically susceptible, and thus readily separated from gangue minerals. Although the roasting process renders the titania fraction insoluble in sulfuric acid, the magnetic ilmenite produced in this manner is not a suitable feedstock for the sulfate process. However, this property can be useful if HCl leaching is employed to selectively remove the iron and other soluble constituents to make synthetic rutile. But the process is only economical if the HCl is regenerated.

With EARS, the regeneration of HCl is performed by pyrohydrolysis in a fluidized-bed reactor. The solid-oxide discharge is in the form of small pellets as opposed to the fine powder of spray systems — an advantage in subsequent handling.

Austpac says its process can make synthetic rutile of 97 wt.% TiO_2 from most ilmenites. The Fe component of roasted ilmenite is highly reactive and very readily leached in hot HCl. Any oxides of Ca, Mg, Mn or Al that occur as impurities within the ilmenite are similarly dissolved. Most of the TiO_2 precipitates back into the grains of synthetic rutile by hydrolysis as hydrated oxychlorides, and is later converted to TiO_2 by calcination.

(*Continued from p. 12*)

is based on sugars as a renewable feedstock. The license agreement allows BASF to build a world-scale production facility that will use the Genomatica process to manufacture BDO based on renewable feedstock. Genomatica will continue to advance its patented, BDO-production-process technology based on sugars while BASF will produce renewable BDO, which will be available in the second half of 2013 for sampling and trials.

Lignin recovery

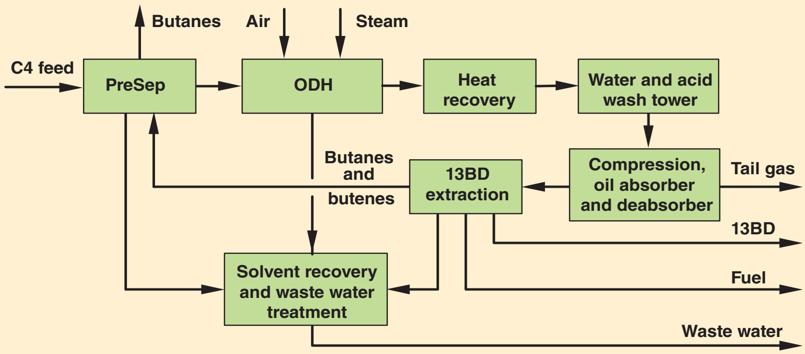
Domtar (Montreal, Québec, Canada; www.domtar.com) has successfully started up a commercial-scale LignoBoost lignin separation plant at its Plymouth, North Carolina mill. This is the first commercial installation of a LignoBoost plant in the world. Domtar's production of BioChoice lignin began in February with a targeted rate of 75 ton/d. Integrated with the pulp mill, the LignoBoost plant separates and collects lignin from the pulping liquor. Lignin is a high-quality bio-based alternative to fossil-fuel based materials, such as fuels, resins and thermoplastics. Separation of a portion of the mill's total lignin production also off-loads the recovery boiler, and allows an increase in pulp production capacity.

The process technology was supplied by Metso Corp. (Helsinki, Finland; www.metso.com). It was originally developed by Innventia (Stockholm), in association with Chalmers University of Technology (both Sweden), and subsequently acquired and further developed by Metso. ❏

A new butadiene process is set for commercialization

China's largest private chemical EPC (engineering, procurement, construction) contractor, Wison Engineering Ltd. (Wison; Shanghai; www.wison.com) has recently introduced details about its proprietary butadiene technology, which is set for commercialization. The process aims to meet the anticipated growth in annual butadiene consumption, which will "far exceed" global expansion in capacity, says Wison's technical director and chief technologist, Yansheng Li. China, in particular, is seeing butadiene demand rising significantly due to the increasing number of synthetic rubber projects, he says.

In Wison's butane process (flowsheet), butanes and lighter components are first separated in the C4 pre-separation unit. Butenes are then mixed with air and steam and dehydrogenated in the oxidative dehydrogenation (ODH) reactor. After recovering the heat, the reaction gas is further cooled and scrubbed to remove acids and other impurities, then compressed. Crude 1,3-butadiene (13BD) is recovered by an absorber/deabsorber unit, and then purified in a 13BD-extraction unit.



The ODH reaction features a new, patent-pending catalyst developed by Wison, which is based on the traditional B-02 (iron-based) catalyst technology. Compared to the traditional catalyst, the new catalyst achieves: a 3–4% increase in the conversion of butane to butene, to reach a conversion of 77–79% in a single-pass; and a 2–3% increase in the selectivity for 13BD, to reach a final selectivity of 92–94%, says Li. He also adds that the improved heat integration leads to a 15% reduction in utility consumption compared to existing technology.

The company has finished preliminary work for several projects in China, and is now in the final stages of completing a process-design package for a 75,000-ton/yr butadiene plant, says Li. ■

CONTROLLING AIR POLLUTANTS

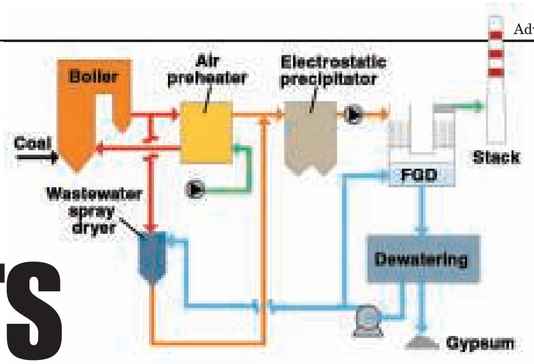


FIGURE 1. Because liquid discharge from wet fluegas desulfurization (WFGD) is of increasing concern for many plants, Advatech offers a wastewater spray dryer as an economical means of achieving zero liquid discharge from wet FGD processes at coal-fired power plants

While it's not always easy to determine what's required for compliance, new technologies can help achieve air-pollution control

Selecting air-pollution control equipment can be tricky. It's not only difficult to determine which pollutants must be controlled, but also which type of equipment will best control them to required levels for any given process or facility because there is no "one-size-fits-all" solution. Technologies that successfully control pollutants in one facility may not work as well in another. Permissible levels in one region sometimes differ from those in another. A similar process may result in different types or levels of pollutants from one plant to the next.

Fortunately, it is possible to solve this puzzle. Experts suggest determining which regulations apply to your facility's pollutants and region; learning about your particular process and the resulting types of pollutants; and, finally, looking, in detail, at the available technologies to figure out which one or which combination will provide the best solution for your worst-case pollution scenario.

Regulations to watch

Regulations concerning mercury, oxides of nitrogen (NOx) and sulfur (SOx), acid gases and particulate matter emissions are of the biggest concern to power plants and some chemical and industrial processors. There are several new or anticipated regulations concerning these pollutants that affected processors need to keep an eye on:

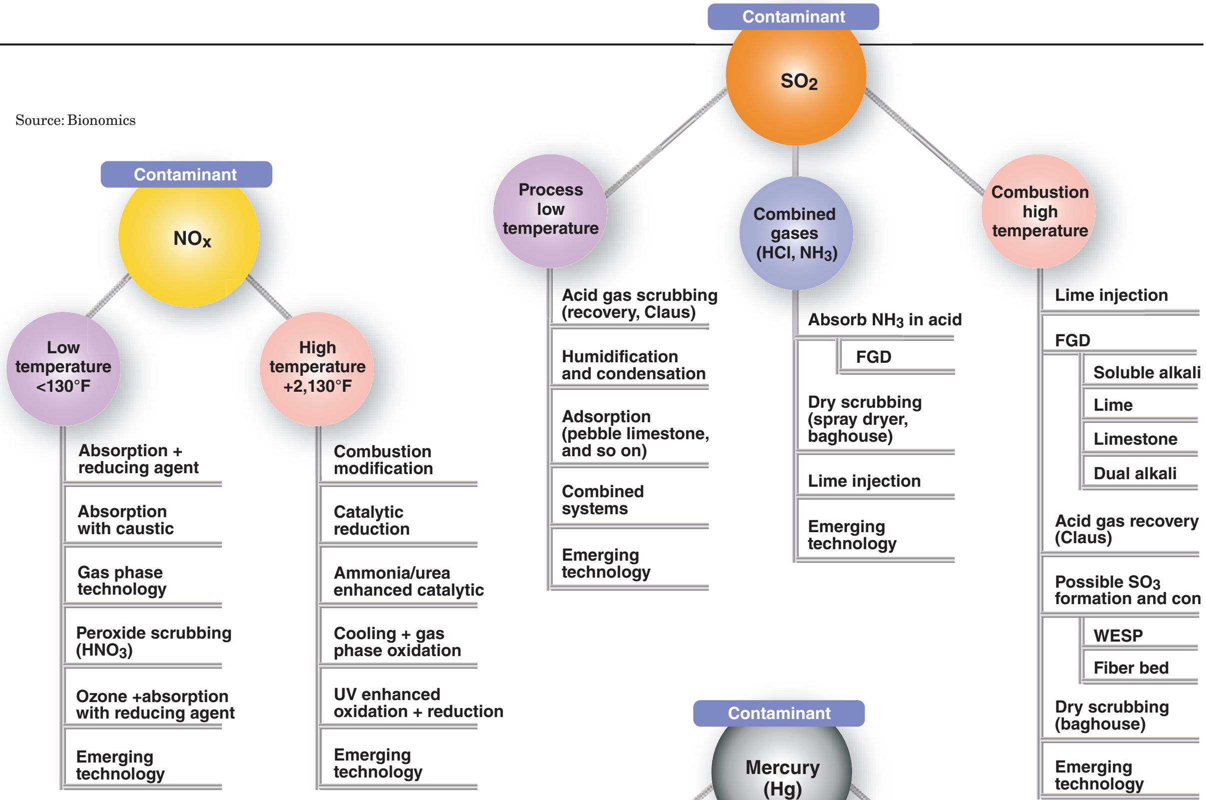
MATS. Revised twice and finalized on March 28, 2013, the U.S. Environmental Protection Agency's (EPA; Washington, D.C.; www.epa.gov) Mercury and Air Toxics Standard (MATS) created updates of emission limits for mercury, particulate matter, SO_2, acid gases and certain individual metals for new power plants. Additionally, certain monitoring and testing requirements that apply to new sources were adjusted. "Two things to know about MATS are that the particulates covered are not what many of us consider 'particulates,'" says Robert Hilton, vice president, power technologies for government affairs with Alstom (Knoxville, Tenn.; www.alstom.com). "They are actually aerosols that are classified by EPA as particulate. The other important thing to know is that the revised standards affect only new coal- and oil-fired power plants that will be built in the future. The update does not change the final emission limits or other requirements for existing power plants."

Interstate Air Pollution Transport. As part of the Clean Air Act (CAA), this "good neighbor" provision requires the EPA, states and processors to address interstate transport of air pollution that affects downwind states' ability to attain and maintain National Ambient Air Quality Standards. Emissions of SO_2 and NOx can react in the atmosphere to form fine-particle ($PM_{2.5}$) pollution. Similarly, NOx emissions can react in the atmosphere to create ground-level ozone pollution. The transport of these pollutants across state borders makes it difficult for downwind states to meet health-based air quality standards for $PM_{2.5}$ and ozone. Recently EPA set dates and locations for meeting with states to discuss regulations regarding air-pollution transport. "What makes compliance with this difficult is that the ruling is technically in limbo," says Hilton. "And this makes it harder to figure out how to control these pollutants, as well as the pollutants regulated by MATS. A lot of what generators need to do to be in compliance with MATS will cover SO_2, which will also be covered by the Interstate Air Pollution Transport rule."

CAA and National Ambient Air Quality Standards. Under the CAA, EPA is required to set National Ambient Air Quality Standards for six common air pollutants and then review those standards every five to six years to determine if the technology to further lower the permissible limits exists and, if so, whether it is actually feasible to achieve these lower levels. "This is expected to happen this year and it is presumed that EPA will attempt to lower acceptable NOx levels," says Hilton. "If this happens, it likely will be further out, in a sequenced implementation plan, with a NOx compliance deadline in the timeframe of 2017 to 2019." Until then, processors in the 23 eastern states must comply with NOx levels currently set by the Clean Air Interstate Rule (CAIR), and the remaining western states must comply with NOx levels currently set by the CAA and regional haze rules.

So how do processors know which regulations impact their facility? "You have to look at all the rules, look at your plant, look at the fuel you burn and where you are located, because

Source: Bionomics



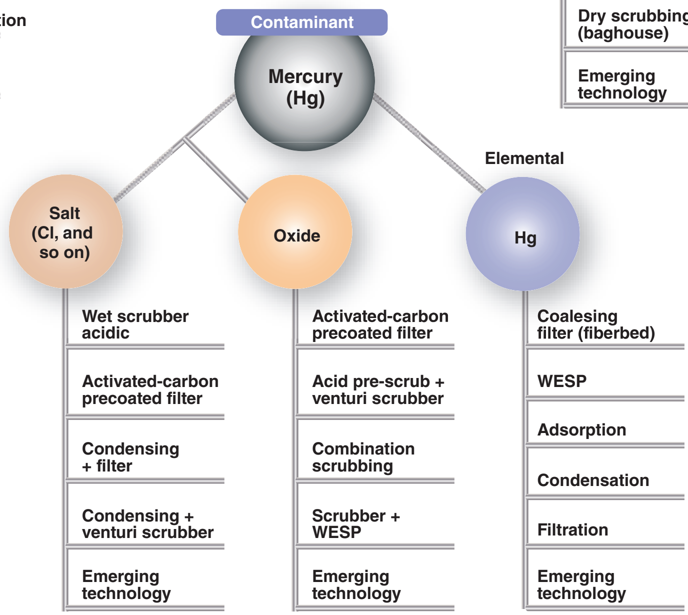


FIGURE 2. Decision trees for controlling a particular air pollutant can help identify the best possible solution for a given plant

some regulations are federal and some are state," says Hilton. "You have to work with both state and federal agencies to find out which regulations your facility is subjected to and which of those are the most applicable and important for your plant and location to obtain the permits it needs to operate. In most cases you have to meet the stricter of the guidelines to be in compliance."

One size does not fit all

"What makes compliance even more challenging is that what might work at one plant, won't necessarily work in another," says Scott Miller, director of engineering technology with Advatech LLC (Austin, Tex.; www.advatechllc.com), a joint venture of URS (San Francisco, Calif.) & MHIA Co. (New York, N.Y.). "Whoever is proposing air-pollution-control technologies needs to be familiar with the plant to maximize total pollution control, from fuel to stack."

Miller suggests first knowing the current emissions. "For example, when looking at mercury, not only is it important to know the total mercury emissions, but also what percentage is in oxidized form, elemental form and particulate form. It's also valuable to know what the speciation is all the way through the back end of the plant, such as at the outlet of the economizer and downstream of the SCR [selective catalytic reduction]."

Understanding the balance of the plant and the impact of each technology being evaluated is also helpful, suggests Miller. For example, to comply with some regulations for mercury and acid gases, many facilities are looking at dry sorbent injection upstream of a particulate control device. It might be possible to achieve regulatory compliance for capture through those technologies, but, as a result, the amount of reagent they have to use could detrimentally impact particulate matter emissions, he explains. Along these lines, disposal must also be considered, Miller urges. For instance, wastewater discharge requirements are expected to be tightened in the near future, which may force emit-

EMBRACING EXISTING AND EMERGING TECHNOLOGIES

The best way to look at the available air-pollution-control technologies is to start with the pollutant.

Particulate matter

For particulates, the commonly used technology is dry electrostatic precipitators. Alternatives to this technology include either low- or high-ratio fabric filters, which will capture finer particulate matter than electrostatic precipitators, but tend to have higher operating and capital costs.

NOx

Most facilities start with low-NOx burners, which are designed to combust coal while starving it of oxygen so that less nitrogen is converted into NOx. Typically, burners alone are not enough, so many facilities add selective catalytic reduction or selective non-catalytic reduction technology.

There have been advances in NOx technology as well. The BioNOxSolver NOx-scrubbing solution (Figure 4) from Bionomic Industries simplifies wet-scrubbing system operation and reduces scrubber system complexity and cost. Low-toxicity BioNOxSolver does not liberate flammable hydrogen sulfide gas at pH use conditions as is typical in NOx sulfide/caustic control chemistries, yet its formulation of nitrogen dioxide reducing agents can achieve over 33% greater removal efficiency with an addition to caustic, says the company.

Robert Richardson, president of Know-NOx (Reno, Nev.; www.know-nox.biz), says his company is offering a unique NOx removal technology for industrial applications, such as: exhaust gas treatment in chemical milling; brightening and pickling of metals; chemical and manufacturing processes that use nitric acid; and cooled stationary-source combustion process fluegas and tail gas from plants; and other sources of waste gas containing NOx.

The process uses a single- or double-scrubbing stage (depending on client requirements) with less than 1.5 s of residence time (treatment time within the scrubber) to treat more than 99% of the NOx (both NO and NO_2) in an ambient-temperature gas stream. Because of the very fast reaction time, the process removal efficiency is tunable to appropriately meet users' compliance requirements and also provide an optimized cost of operation. This process, which uses chlorine dioxide gas in a new way, is less expensive to install and operate than currently available industrial technologies for NOx treatment, according to Richardson. "The single- or two-stage process has the ability to produce higher removal efficiency than can be obtained from conventional two-, three- and six-stage scrubbing systems, using a smaller equipment footprint," he says. "The reason we can reach greater than 99% for both NO and NO_2 is because we can cost effectively increase residence time. The technology removes more NOx in 1.5 s than conventional wet scrubbing technology can do in 5 to 120 s of residence time."

SO_2, SO_3 and acid gases

These pollutants have the largest fleet of control technologies available. What is used typically depends on the level of removal required, but typical equipment includes wet or dry fluegas desulfurization (FGD) or, possibly, duct-injection processes.

Because liquid discharge from wet FGD (WFGD) is of increasing concern for many plants, Advatech offers a Wastewater Spray Dryer (WSD; Figure 1) as an economical means of achieving zero liquid discharge (ZLD) from WFGD processes at coal-fired power plants. The WSD makes use of waste heat in the fluegas to completely evaporate the purge stream from the WFGD process. The WSD consists of a spray dryer installed in a small slipstream that bypasses the air heater. The differential pressure across the air heater provides the motive force for the fluegas, so in most cases, a fan is not needed. The liquid purge from the WFGD process (in the form of filtrate) is added to the spray dryer through either dual-fluid nozzles or a rotary atomizer. The chlorides and other dissolved substances present in the purge stream form solid particulate in the WSD, which are then removed from the fluegas, along with the fly ash, in the existing particulate-control device. By retaining the ability to purge chlorides from the WFGD, the process can be controlled to chloride levels for which materials of construction are more compatible, and process performance is maximized.

Mercury

Mercury can often be controlled via pre-combustion or combustion additives, such as bromine injections, which change the mercury into a form that is more easily captured in a wet scrubber. An alternative to this technology is activated carbon, which captures, absorbs and holds the mercury until it is collected in a particulate device (as opposed to a scrubber).

However, circulating dry scrubbers are becoming a popular technology in this area because they are effective at collecting mercury, as well as acid gases and aerosols or very fine particulates, says Hilton. "These dry scubbers are often considered multi-pollutant devices."

Alstom's solution in this area is the NID system, comprised of a hydrator/mixer, J-duct reactor and, typically, a fabric filter. The NID can be used with electrostatic precipitators, as well. In the J-duct reactor vessel, SOx, acid gases and mercury react with quick or hydrated lime under humid conditions. Once bound to the particulate matter, the gaseous pollutants are removed from the fluegas in a downstream particulate collection device. The collected particulates are recycled to the mixer where fresh lime and water are added to the process. The inclusion of the integrated hydrator/mixer eliminates the need for slurry handling, simplifying the operations, maintenance and power requirements of the process. The high rates of sorbent recycling also contribute to the low cost and high efficiency of the NID process. ❑

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ters to use zero-liquid discharge technologies or install expensive wastewater-treatment processes.

"Based on all these considerations and different processes at each facility, it is just not possible to buy an item off the shelf and have the problem go away," says Ken Schifftner technical director with Bionomic Industries Inc. (Mahwah, N.J.; www.bionomicind.com). Instead, he suggests using a "decision tree" to determine the best possible solution. (Figure 2).

"The 'decision tree' should start with the contaminant," he says. "In the case of NOx, the contaminant may be emitted at high temperature (favoring insoluble NO) or low temperature (favoring soluble NO_2, N_2O_4 and so on), or the gas mixture could contain a variety of NOx species. We usually start with a request for an NO-to-NO_2 ratio test report. Based on this information, there are a variety of possible

Bionomic Industries

FIGURE 4. The BioNOxSolver NOx scrubbing solution from Bionomic Industries simplifies wet-scrubbing system operation and reduces scrubber system complexity and cost

technologies to apply." (The logic tree lists just a few.)

A similar process should occur for SO_2, says Schifftner. The emission could come from a process or be combined with other gases or from combustions. "We usually start with a questionnaire that helps define the emission source," he says. In the case of a process-emission source, perhaps wet scrubbing with caustic can be used. If the SO_2 must be recovered, humidification (or scrubbing with sulfuric acid) can be applied. If the SO_2 concentration is low, sometimes humidifying then passing the gases through a bed of pebble lime or limestone can be used. Sometimes lime or limestone is injected into the ductwork (or even into the boiler) to control SO_2. If ammonia is also present, the ammonia is removed first. If the source is from combustion, various proven FGD technologies are available. If SO_3 (aerosol forms), the problem shifts from gas absorption to aerosol capture, thus a fiberbed or wet electrostatic precipitator (WESP) is often used.

"For mercury, it can get complicated," warns Schifftner. "We start by determining the state of the mercury as it leaves the source." If the mercury is elemental and at high concentration, the mercury could possibly be condensed and recovered. Perhaps it could be adsorbed onto carbon or a zeolite. If the mercury leaves the process as a salt (usually a chloride), it is often possible to use wet scrubbing, since the salt is soluble. At times, gas cooling followed by scrubbing is used. If the mercury is emitted as an oxide, to use wet scrubbing, usually conversion to a soluble salt is required. This is done by using an acidic first stage. That stage may be followed by a venturi scrubber and possibly a WESP. If the mercury comes from a combustion source, the mercury is usually in the form of an oxide and an activated-carbon precoated baghouse might be appropriate. If the mercury arrives along with SO_2 or HCl, the

PULLING IT ALL TOGETHER

While it may seem like a lot of disparate technologies are available, most can and do work together to reduce multiple pollutants and keep facilities in total compliance. Consol Energy Inc. Research & Development (Pittsburgh, Pa.; www.consolresearch.com) leads teams that work in conjunction with power plants and power companies to install and test pollution control systems to determine whether it is possible and feasible to be in compliance using a variety of technologies.

One example includes the Greenidge Multi-Pollutant Control Project. Consol worked with AES Greenidge LLC (Dresden, N.Y.; www.aes.com) and Babcock Power Environmental (Worcester, Mass.; www.babcockpower.com) to install and test an integrated multi-pollutant control system on one of the nation's smaller existing coal-fired power plants — the 107-MW_e AES Greenidge Unit 4.

The multi-pollutant control system included a hybrid selective non-catalytic reduction/selective-catalytic reduction system and a circulating fluidized-bed dry scrubbing system. The overall goal of the 2.5-yr project, which was conducted as part of the U.S. Department of Energy's Power Plant Improvement Initiative, was to demonstrate that this multi-pollutant control system could cost-effectively reduce emissions of NOx, SO_2, mercury, acid gases and particulate matter from coal-fired electric generating units.

Performance testing data collected during the project showed average removal efficiencies of 96% for SO_2, 95% for SO_3, 97% for HCl and 98% for mercury. NOx emissions were reduced by more than 50% and particulate-matter emissions were reduced by more than 98% relative to the emission rates achieved prior to installation of the technology.

Other examples of control technologies at work can be seen on Consol Energy Inc. Research & Development's website at www.consolresearch.com/pollution/pollution-control.html. ❑

baghouse precoat may include lime or limestone.

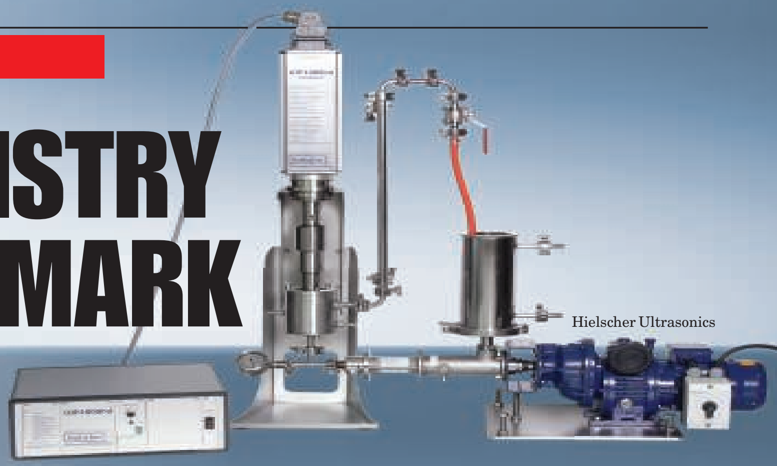
The codes basically dictate not only the technology, but also how many stages are used, says Bionomic's Schifftner. For example, years ago, a hazardous-waste incinerator may have used a quencher, venturi scrubber and absorber to meet codes. Now, it may need a WESP on the end to control that very small amount of residual particles. If mercury is present, the quencher may be run highly acidic (to convert the Hg to chloride), then the venturi, the absorber and the WESP are used.

"No one ever bought these products because they wanted to," says Hilton. "It's a get-out-of-jail-free card and a difficult one to obtain at that. But at the end of the day, it is possible to meet the regulatory requirements for air-pollution control if you employ the right equipment." ■

Joy LePree

SONOCHEMISTRY MAKES ITS MARK

Once considered a novelty for niche applications, sonochemistry has blossomed into many CPI sectors



Hielscher Ultrasonics

FIGURE 1. The UIP1000 processor from Hielscher Ultrasonics has a power of 1,000 W and operates at 20 kHz

Industrial uses of high-intensity ultrasound have grown tremendously over the past 25 years, says Kenneth Suslick, professor of chemistry at the University of Illinois at Urbana-Champaign and one of the pioneers in the field. Ultrasonic welding of plastics is universal, ultrasonic cleaning of equipment has replaced most solvent and vapor degreasing, and it is even routine for homes to have ultrasonic humidifiers, either built-in or portable. The use of ultrasound for chemical processing, too, has found a permanent niche in industrial applications, including sonocrystallization of pharmaceuticals, enhancement of high-value-added chemical reactions, well-water purification, and preparation of ultrafine emulsions for cosmetics. Many other large-scale applications are developing as well in the food industry, says Suslick.

Thirty years ago, sonochemistry was a black art, unknown to nearly all chemists, and understood by no one. Today we understand in detail the nature of acoustic cavitation and most of the mechanisms responsible for sonochemical reactions, Suslick continues. "Our understanding of the extraordinary conditions produced during cavitation, created by the implosive collapse of microscopic gas bubbles in liquids, is thorough. We can measure and control the temperatures and pressures of cavitation that drive sonochemical reactions."

In fact, biodiesel production, water and wastewater purification, and sonocrystallization of pharmaceuticals, are among the most successful applications of sonochemistry.

Biodiesel production

Making biodiesel fuel from vegetable oils — such as soy, canola, Jatropha or sunflower seed — or animal fats, involves the base-catalyzed transesterification of fatty acids with methanol or ethanol to obtain either methyl or ethyl esters. Glycerin is a byproduct of those reactions. The heavier glycerin will sink to the bottom and the biodiesel fuel floats on top and can be separated by decanters or centrifuges.

The traditional esterification reaction in batch processing tends to be slow, and separation of the glycerin can take several hours. The batch process mixes various chemicals together mechanically.

When ultrasound is used, however, the ensuing cavitation provides the kinetic energy needed for faster and more complete esterification. Cavitational shear also reduces the size of methanol or ethanol droplets, resulting in improved methanol and catalyst utilization. Thus, less methanol and catalyst are required.

As opposed to batch operations, ultrasonic biodiesel processing allows for continuous inline processing and ultrasonic reactors reduce the processing time from the conventional 1–4 h to less than 30 s. Ultrasonication also reduces the separation time from the 5–10 h required for conventional agitation, to less than 60 min, says Scott Weis, owner of Wisconsin Fluid Systems LLC (Union Grove, Wisconsin www.wisconsinfuels.com).

Ultrasound also allows a reduction in the use of heat and pressure, two of the largest energy costs of batch plants.

"We've had good experiences with ultrasound for continuous-flow biodiesel production," says Weis. "The best advantages are that it is a faster reaction, less energy is used, it requires a smaller process area, and requires less material with a flammable mixture of methanol," he says.

"The setup process was purely trial and error [with batch reactors]. With a continuous flow system it is fast and easy to make adjustments."

The throughput for most of the company's systems is 450 to 600 L/h. The frequency and flowrate vary, depending on the feedstock.

Genuine Bio-Fuel Inc. (Indiantown, Fla; www.genuinefuel.com) has had a similar experience. "Batch reactors are too cumbersome and limiting," says the company's executive vice-president Jeff Longo. "The batch process is time-consuming, taking anywhere from a couple of hours to days to complete. Plus, it is not conducive to using a variety of alternative feedstocks of variable quality," he says. Using ultrasonics allows the company to produce greater quantities of finer-quality biodiesel fuel, while reducing costs and enabling the company to use a wide variety of feedstocks.

Genuine Bio-Fuel spent 18 months procuring proprietary data, which gives the proper flowrates, catalyst percentage, and injection rates along with the proper frequencies to be applied.

Genuine Bio-Fuel has used the UIP1000hd – 1 kW, 20 kHz industrial ultrasonic processor (Figure 1) from Hielscher Ultrasonics GmbH (Teltow, Germany; www.hielscher.com), de-

ULTRASOUND SOURCES

The following companies offer equipment and services related to the use of ultrasound:

1. **Ultrawaves GmbH** (Hamburg, Germany; www.ultrawaves.de); reactors systems and consulting for treatment of water, wastewater and biomass
2. **Hielscher Ultrasonics GmbH** (Teltow, Germany; www.hielscher.com); ultrasonic reactors for applications such as biodiesel production, and wastewater and biomass treatment.
3. **Meinhardt Ultraschalltechnik** (Leipzig, Germany; www.meinhardt-ultraschall.de); ultrasonic transducer/generator systems
4. **Ultrawave Ltd.** (Cardiff, U.K. www.ultrawave.co.uk); precision ultrasonic cleaning equipment
5. **Branson Ultrasonics** (Danbury, Conn.; www.emersonindustrial.com); precision cleaners
6. **Honda Electronics Co.** (Tokyo, Japan; www.honda-el.co.jp); ultrasonic reactors
7. **Industrial Sonomechanics, LLC** (New York, N.Y.; www.sonomechanics.com); nanocrystallization of pharmaceuticals
8. **Stoelting Ultrasonics** (Kiel, Wisconsin; www.stoeltingcleaning.com); custom cleaning
9. **Telsonic AG** (Bronschhofen, Switzerland; www.telsonic.com); generators, tube resonators, transducers, cleaning
10. **Ultrasonics Australasia Pty Ltd.** (Sydney, Australia; www.ultrasonicsaustralasia.com.au); ultrasonic cleaning
11. **Unisonics Australia Pty Ltd.** (Sydney, Australia; www.unisonics.com.au); ultrasonic cleaning
12. **U&Star Ultrasonic Technology** (Hangzhou, China; www.ustar-ultrasonic.com); ultrasonic accessories and reactors, consulting

signed for continuous processing at high flowrates.

Wastewater treatment

While ultrasound in biodiesel fuel processing works mainly by providing the shearing forces that greatly speed up the chemical reactions, additional effects are involved in ultrasonic wastewater treatment. Here the aim is to reduce the amounts of pollutants, including nutrients and potentially pathogenic micro-organisms. Low frequency, high-intensity ultrasound can break up various pollutants, and even break up bacteria. The ultrasound destroys bacterial cells, causing them to spill out their contents and endo-enzymes, which are then consumed by other bacteria that become more effective at degrading the organic pollutants. The pollutants, having been broken down by the ultrasound, become easier to degrade.

The ultrasonic treatment allows the disintegrated sludge to be used as an internal electron donor to fuel the denitrification stage. A sufficient carbon concentration is needed to remove nutrients from wastewater through the biological nutrient-removal process.

Several wastewater treatment plants have installed ultrasonic treatment. One of the latest is the wastewater treatment plant at Schleswig, Germany, which had an ultrasound system installed in March 2011 by Ultrawaves GmbH (www.ultrawaves.de). The company has its roots in the R&D work pursued in Germany at the Northern Institute of Technology, situated on the campus of the Hamburg-Harburg University of Technology. It was founded by professor Uwe Neis and Klaus Nickel.

The company's reactor for sludge disintegration is a compact machine with a volume of 28 L. The standard model is normally fitted with five oscillating units that can be supplied with up to 2 kW each. This reactor is capable of treating a sludge flow of up to 30 m^3/d.

The company says the reactor decreases digestion time by up to 60%, reduces the digested sludge mass by up to 30% and produces up to 50% more biogas.

The plant at Schleswig has a design capacity of 75,000 PE (persons equivalent). The system has a power of 5 kW. About 30% of total thickened, waste-activated sludge flow is treated with ultrasound. Compared with the start-up phase of the ultrasound application, the volatile solids degradation was increased from 57% to 66%. From May 2011 to March 2012, the specific biogas yield has also been improved by 32%.

A more recent wastewater-treatment plant is in the town of Maroochydore, in the Sunshine Coast of Queensland, Australia. There, the ultrasonic units were installed by Royce Water Technologies Pty Ltd. (Albion, Queensland; www.roycewater.com.au), the Australian representative of Ultrawaves.

The plant has "A" and "B" bioreactors. The methanol dosing to "A" plant was turned off in February while plant "B" continued dosing. The sonicated, thickened sludge has been successful in maintaining low nitrate levels in plant "A" effluent without the addition of methanol as a carbon source.

The trial will continue for another two months to assess what effects sonication has on sludge drying and disposal volume.

Industrial Sonomechanics

FIGURE 2. The BSP-1200 ultrasonic processor from Industrial Sonomechanics is designed for batch and flow-through processes and pilot-scale production. The processor outputs up to 1,200 W of acoustic power and operates at 20kHz

Food processing

Another effect of acoustic cavitation that has been successfully exploited is particle size reduction in food processing. One of the most recent breakthroughs was achieved by a team from Dairy Innovation Australia Ltd. (Werribee, Victoria; www.dairyinnovation.com.au), and the School of Chemistry, University of Melbourne (www.unimelb.edu.au), led by professor Muthupandian Ashokkumar. The team has used a continuous sonication process at 20 kHz that is capable of delivering up to 4 kW of power with a flow-through reactor design to treat dairy ingredients at flowrates from 200 to 6,000 mL/min. Dairy ingredients that have been treated include reconstituted whey protein concentrate, whey protein and milk protein retentates and calcium caseinate.

Sonication of solutions with a contact time between 1 and 2.4 min led to a significant reduction in the vis-

Professor Kenneth Suslick

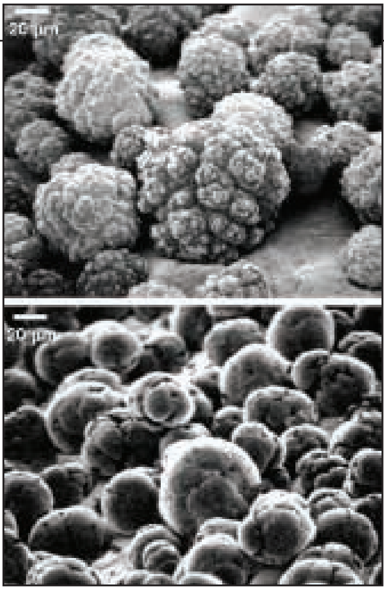


FIGURE 3. This scanning electron micrograph shows the effect of ultrasonic irradiation on the surface morphology and particle size of nickel powder. Upper image is before ultrasound and lower is after irradition of a slurry in decane. High-velocity interparticle collisions caused by ultrasound are responsible for the smoothing and removal of a passivating oxide coating

CONFERENCE NOTE

The 1st meeting of the Asia-Oceania Sonochemical Society will take place at the University of Melbourne on July 10—12. The meeting will be be chaired by Ashokkumar, with participants from China and Japan, as well as from Australia, the U.S. (Suslick), and the U.K. (Mason).

cosity of materials containing 18 to 54% (w/w) of solids. The viscosity of aqueous dairy ingredients was reduced by between 6 and 50% depending on the composition, processing history, acoustic power and contact time, says Ashokkumar.

The team also noticed an improvement in the gel strength of sonicated and heat-coagulated dairy systems. When sonication was combined with a heat treatment, the heat stability of dairy ingredients containing whey proteins was improved. The gelling properties and heat stability were maintained during spray drying and upon reconstitution.

Ashokkumar says: “The financial viability of the Australian dairy industry relies heavily on the manufacture and export of milk powders and dairy protein concentrates. The acoustically generated chemical and physical effects were used to modify the functional properties of dairy proteins. Transformation of the sulfur-containing proteins by this means may overcome many of the difficulties currently encountered in thermal processing of whole milk and whey proteins. Further, the resulting dairy products can be marketed as specialty hydrogel-based dietary products, microcapsules, and medical ultrasound contrast agents.”

Sonocrystallization

Apart from food processing, ultrasonics has become a major tool in particle-size reduction down to the nano-scale (nanocrystallization) in the pharmaceutical industry. High-powered ultrasound can assist the crystallization process by influencing the initiation of crystal nucleation, controlling the rate of crystal growth, ensuring small and even-sized crystals are formed, and preventing fouling of surfaces by newly formed crystals.

A large number of currently available drugs exhibit poor water solubility, leading to reduced bioavailability and increased potential of side effects. Particle-size reduction has been shown to increase the bioavailability and reduce the required dose frequency, decreasing drug side-effects.

The process of nanocrystallization requires the application of very high ultrasonic amplitudes to particle suspensions, which produces extreme shear forces.

Industrial Sonomechanics, LLC (New York, NY; www.sonomechanics.com), offers bench and industrial-scale, high-power ultrasonic processors for the production of nanosized drug crystals (Figure 2). The processors are based on its Barbell Horn Ultrasonic Technology.

The company says the process of ultrasonic nanocrystallization requires extremely high ultrasonic amplitudes to be applied to particle suspensions in order to produce extreme shear forces. Conventional high-power ultrasonic technology forces all processes to run either at a small scale and high amplitude or a large scale and low amplitude, according to Industrial Sonomechanics, which limits the commercial implementation of high-power ultrasound to processes for which low amplitudes are sufficient, such as cleaning, simple deagglomeration, mixing and macro-emulsification. The company says it has overcome this limitation by developing the Barbell technology.

For example, the company said, ultrasonic amplitudes of the order of 100 microns can only be reached by conventional horns when their output tip diameters do not exceed about 20 mm (laboratory scale). Conventional horns with output tip diameters of 40 mm and above (industrial scale) operate at the maximum amplitude of about 25 microns, irrespective of the specified system power.

Barbell horns are able to amplify ultrasonic amplitudes while retaining large output tip diameters.

Other applications

In addition to these successful applications of ultrasound, many more are predicted to become important in industry. Another pioneer in the field of sonochemistry, Timothy Mason, professor of chemistry and director of the Sonochemistry Applied Research Center at Coventry University (U.K.; www.coventry.ac.uk.) sums up what he believes will be the main areas of influence of sonochemistry in industry, as follows:

- ***Benefits in synthesis.*** Use of less hazardous chemicals and environmentally friendly solvents; minimizing the energy consumption for chemical transformations; using alternative or renewable feedstocks
- ***Benefits in electrochemistry***. Continuous cleaning and activation of the electrode surfaces; degassing, which limits gas bubble accumulation on the electrode surface; agitation (via cavitation), which disturbs and reduces the thickness of the diffusion layer; agitation, which also stops the depletion of electroactive species in the immediate vicinity of the electrode
- ***Benefits in materials science.*** Improvement in the preparation, modification and coating of nanoparticles; surface modification of materials (Figure 3); improvements to crystallization processes
- ***Environmental protection.*** Cavitation weakens bacterial cell membranes, rendering them more susceptible to biocides; the production of radical species such as hydroxyl radicals provides the essential elements for both the chemical and biological decontamination of water; enhanced advanced oxidation processes, for instance ultraviolet radiation, ozone or chemical oxidants ■

Paul Grad

FOCUS ON

Explosion Protection

Hoerbiger Ventilwerke

This flowrate totalizer has an explosion-proof enclosure

The PD6830 ProtEX-RTP Pulse Input Rate/Totalizer (photo) has a rugged, explosion-proof, NEMA 4X enclosure and is designed for the quick and easy display of local or remote flow information in hazardous areas. The SafeTouch through-glass buttons allow operation without removing the cover. Flowmeter k-factor units are automatically converted to the desired display units. The meter has FM, ATEX, CSA, IECEx and CE approvals. — *Precision Digital Corp., Holliston, Mass.*
www.predig.com

Ashcroft

Infastaub

A new generation of relief valves for explosion-pressure venting

EVN 2.0 (photo) is this company's latest generation of relief valves. It combines a number of technical innovations, offering maximum reliability in flameless explosion-pressure venting. The EVN 2.0 combines the latest standard, according to EN 16009, with the proven benefits of vacuum-proof, nearly maintenance-free construction. The EVN 2.0 is available in different materials, ranging from standard carbon steel to a stainless-steel variant for the food industry. A variety of O-ring materials is also available to match a wide range of applications. — *Hoerbiger Ventilwerke GmbH & Co. KG, Vienna, Austria*
www.hoerbiger.com

Precision Digital

Accurate pressure transmitters for hazardous areas

The A2, A2X and A4 pressure transmitters (photo) are heavy-duty sensors with accuracies up to ±0.25% full scale. The A2 is available with a wide variety of electrical connections, analog output signals and pressure ports for most industrial applications. The A2X (explosion- and flame-proof) and A4 (intrinsically safe) configurations are designed for hazardous environments. — *Ashcroft Inc., Stratford, Conn.*
www.ashcroftinc.com

Cartridge filters proven safe for hybrid mixtures

The pressure-shock-resistant cartridge filter MPR was designed for the filtration of sticky and lung-current, harmful or toxic dusts as well as suspended matter or powders with active pharmaceutical ingredients (APIs). An additional risk potential is caused by hybrid mixtures that might result from solvent-containing substances in the pharmaceutical industry. Explosion tests (photo) have now demonstrated that the MPR also copes with extreme explosion conditions under which it can be safely operated. The filter is equipped with constructive measures for explosion protection. Therefore, explosion overpressure of only 1 barg (maximum) can be measured inside the filter, in spite of missing explosion pressure relief. A special flame filter is mounted inside to prevent flame spread on the clean gas side. — *Infastaub GmbH, Bad Homburg, Germany*
www.infastaub.de

FB dryers with automated explosion-suppression systems

Vibrating fluidized-bed (FB) dryers (photo, p. 25) and coolers from this manufacturer are available with an optional, high-pressure design to accommodate the addition of third-party,

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

Witte

Pepperl+Fuchs

automated explosion-suppression systems. Offered upon request, the sealed design features reinforced 12-gage steel throughout plus 25% more clamps than on standard designs to handle the rapid pressure increase that occurs when an explosion suppression system is triggered. Covers, pans and panels remain safely intact, says the company. The FB coolers and dryers are specified when drying food, chemical, pharmaceutical, mineral and other products that may generate combustible, fine particles and airborne dust (such as sugar, corn starch, clay, aluminum and fertilizer). — *Witte Co., Washington, N.J.*
www.witte.com

The CV-S explosion vent now has a rectangular shape

This company has released the rectangular version of its popular CV-S explosion vent. Specifically designed to provide non-fragmenting opening when protecting industrial process equipment, the CV-S explosion vent is said to provide superior protection in applications such as air-material separation, drying, conveyance and processing operations. The CV-S vent is designed to support robust cycling and applications where the operating pressure approaches the burst pressure, or where moderate vacuum pressure exists. The rectangular shape is available in sizes ranging from 9 × 12 in. up to 44 × 69 in., as well as metric and custom sizes. — *Fike, Blue Springs, Mo.*
www.fike.com

Cabinets, enclosures and process interfaces for Ex areas

This company's global network of explosion-protection specialists and engineers, as well as more than 60 years experience form the knowledge database that makes it a leading company when dealing with explosion-hazardous areas. A recent example is the invention of DART (dynamic arc recognition and termination), which detects a spark caused by opening or closing an electric circuit, and switches off the circuit within a few microseconds. Thus even at higher power levels, sparks never become inductive. Within the FieldConnex product line, several DART fieldbus modules are already available, but there are also new developments with remote I/O

systems and intrinsic safety barriers (photo, p. 25). — *Pepperl+Fuchs, Inc., Twinsburg, Ohio*
www.am.pepperl-fuchs.com

Load reactors safely with this vacuum conveying system
The INEX vacuum-conveying reactor loader (photo) uses a patent-pending nitrogen purging function, which reduces the oxygen content within the unloaded batch to below 7% (or lower when required), thereby maintaining the material's inert safety while providing dust-free transport. Used for the vacuum transfer of dry or wet powder and granules into potentially hazardous conditions, the INEX features a closed station that can be flushed from within by sucking in the washing liquid through WIP/CIP. Standard lightweight and pressure rated systems are available with INEX functionality. — *Volkmann, Inc., Hainesport, N.J.*
www.volkmannusa.com

Volkmann

Explosion protection for spray dryers
The flat bursting panel Ex-Go-Vent-Hyp has been developed for hygienically demanding applications found in the food-processing and pharmaceutical industries. The smooth surface, in connection with the patented, full-surface and tapered sealing concept, enable the implementation of these special bursting panels in critical plants, such as spray dryers with (or without) wet cleaning, fluidized-bed dryers, filters and mixers. — *Rembe GmbH, Brilon, Germany*
www.rembe.de

Flange heaters for use in Ex 'd' areas
This company's tubular flange heater has received additional IEC Ex "d" flameproof certification. Some available features include capabilities for Ex d IIC: T1-6 Gb, operation up to 80°F and enclosed anti-condensation heaters. These heaters are designed for heating liquids and gases in tanks, pressure vessels, vaporizers and similar equipment for applications from 40 to 4,000 kW. They are made with Watrod or Firebar tubular elements that are brazed or welded to a flange. — *Watlow, St. Louis, Mo.*
www.watlow.com ■

Gerald Ondrey

JUNE New Products

Parker Hannifin

Larson Electronics

Swagelok

Flexitallic

Many valve types are featured in this new product line

The IPT Series of products includes a range of valve types for medium- and high-pressure valves, fittings and fluid control devices (photo). Products in the IPT Series are constructed from cold-worked, 316 stainless steel, annealed 316 stainless steel and other corrosion-resistant special alloys. The medium- and high-pressure IPT line includes check valves with maximum pressures up to 60,000 psig, ball valves that accommodate applications up to 20,000 psig, relief valves to handle up to 20,000 psig and needle valves available in six body types, along with tubing, coned and threaded fittings and associated tools and accessories. — *Swagelok Co., Solon, Ohio*
www.swagelok.com

Seal damaged flanges with this compressible gasket

The Flange Rescue Gasket (FRG; photo) can be applied to seal damaged flanges and avoid the need for replacing or machining the flange. The FRG can reduce the time-consuming and costly process of flange maintenance, especially in corrosive offshore environments. The FRG is fabricated from highly compressible Sigma PTFE (polytetrafluoroethylene) to ensure that the FRG conforms to the damaged flange surface to seal and prevent further deterioration. The bright-colored, easily identifiable FRG has a fluoropolymer-coated body that is corrosion-resistant. The unit features integral bolt holes for ensuring correct location and making installation easy, the company says. — *Flexitallic Ltd., West Yorkshire, U.K.*
www.theflexitallicgroup.com

This emergency exit sign is explosion-proof

The EXP-EMG-EXT-12W-1LX Explosion-proof Emergency Exit Sign (photo) is designed to provide failsafe operation and a pathway to safety in the event of unexpected power failures. The sign is approved for use in Class 1, Div. 1 and Class 2, Div. 1 and 2 areas, and complies with all hazardous location regulations for emergency explosion-proof lighting. It will run for 90 min when the main power sources are shut down unexpectedly. The unit features an LED-powered exit sign and a high-performance nickel-cadmium battery. — *Larson Electronics LLC, Kemp, Tex.*
www.magnalight.com

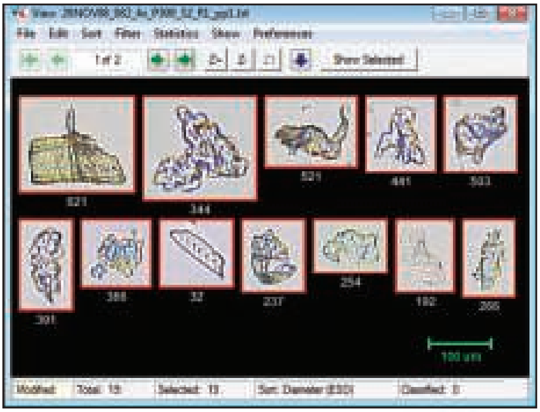
Handle up to 5,500 psi with these hoses

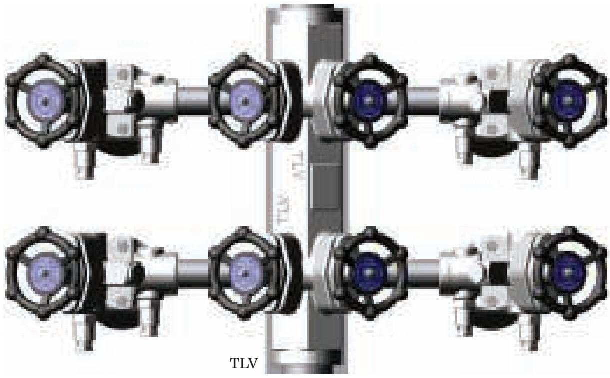
High-pressure hose assemblies (photo) are available from this company to handle working pressures as high as 5,500 psi, while maintaining peak flowrates. The 944B and 955B high-psi assemblies are manufactured with a heavy wall of PTFE that has excellent compatibility with a variety of media, including corrosive chemicals, such as acids and newer hydraulic fluids, the company says. Also, the PTFE tubes have a static-dissipating liner that provides a pathway for static electricity dissipation to the end fittings for applications where flow-induced electrostatic charges could build up and potentially damage the hose and surrounding environment. The hoses are braided with 304 stainless steel to allow flexibility and a tighter bend radius while maintaining high working pressures. Sizes range from 0.25- to 1-in. inner dia. — *Parker Hannifin Corp., Fort Worth, Tex.*
www.parker.com

Verify the effectiveness of rinsing with this device

The FlowCam-ES imaging particle analysis system is designed to automatically detect, image, count and measure metal particles in rinse water to verify the effectiveness of the rinse step in removing contaminants. Operating online within the production line, the FlowCam automatically

Fluid Imaging Technologies



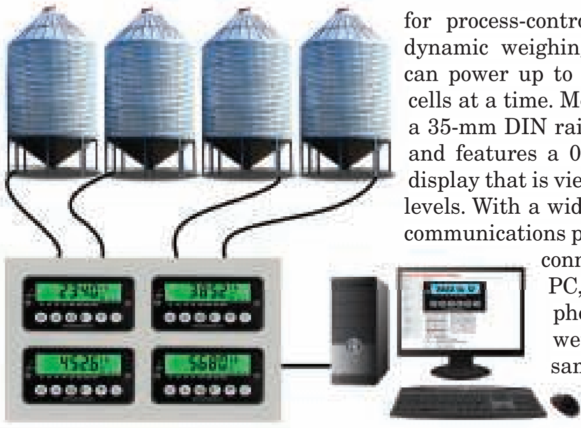


TLV

extracts, dilutes and runs samples of the wash water. The device also takes a high-resolution digital image of each particle detected (photo). The inline FlowCam images thousands of metallic particles in seconds to quickly test and document whether surface contamination levels after rinsing meet required specifications to advance to the packaging area. The FlowCam technology is ideal for testing wash water from pumps, silicon wafers, laboratory glassware and other high-purity products, says the company. — *Fluid Imaging Technologies Inc., Yarmouth, Maine*
www.fluidimaging.com

This single-use mixer is cost-effective

The HyPerforma Single-Use Mixer DS300 system gives users the ability to mix, store and ship material in the same container. The unit consists of a docking station with an adjustable, top-mounted, angled mixing system for either a single-use bioprocess container bag or liner in a stainless-steel or standard plastic drum. The HyPerforma is designed to be cost-effective for pilot-scale liquid preparations for the manufacture of vaccines and biological products. Featuring the same proven mixing system as in related products from this company, the HyPerforma DS300 can be used for mixing buffers and media, from liquid-to-liquid and powder-to-liquid, as well as re-suspension applications. It uses the same docking station for sizes from 50 to 300 L. — *Thermo Fisher Scientific Inc., Waltham, Mass.*
www.thermofisher.com



Cardinal Scale Manufacturing

These steam manifolds minimize installation space

MP Series piston manifolds (photo) are Class 800 forged manifolds available with four, eight or twelve stations. Each connection point has a built-in piston valve, minimizing the amount of space required for installation. MP Series manifolds contain a high-performance, Class 800 (maximum pressure is 1,098 psig at temperatures up to 800°F) piston valve comprised of upper and lower valve rings made of alternating layers of stainless steel and graphite that provide exceptionally tight sealing. The MP Series is available at a lower price level than bellows-style manifolds, making it an ideal choice for large-project work, the company says. — *TLV Corp., Charlotte, N.C.*
www.tlv.com

Power up to eight load cells with this instrument

The Model 201 weight transmitter (photo) is a fast, accurate instrument for process-control-based static and dynamic weighing applications, and can power up to eight 350-ohm load cells at a time. Model 201 comes with a 35-mm DIN rail mounting bracket, and features a 0.5-in.-high, six-digit display that is viewable at all lighting levels. With a wide range of standard communications protocols, it is easy to connect the device to a PC, PLC or other smartphone. The Model 201 weight indicator offers sample rates of up to 200 samples per second. — *Cardinal Scale Manufacturing Co., Webb City, Mo.*
www.cardinalscale.com

New capabilities for this pipe-stress software

A recently launched version of the Caesar II pipe-stress analysis software has been updated with significant new and extended capabilities, including an enhanced interface for SmartPlant 3D model import and export. In addition, the updated version has added a Japanese-language interface, and seismic-code and spring-hanger database capabilities. The easier import and export of pipe-stress analysis results to other programs allows users to share information seamlessly in a collaborative work environment, the company says. Information sharing between pipe-stress engineers and piping designers reduces errors and the user's capital expense, it adds. — *Intergraph Corp., Huntsville, Ala.*
www.intergraph.com ■

Scott Jenkins

CHEMICAL ENGINEERING
FACTS AT YOUR FINGERTIPS
Department Editor: Scott Jenkins

Solids Conveying

Dry, granular solids can be conveyed in a number of ways. Two common devices for transporting granular solids are the angular-pitch vibrating conveyor and the horizontal differential-motion conveyor. The variability in the design and performance between the two types stems from the differences in the kind of motion required to move the mass in one direction. The most significant difference between the two solids-conveying systems is the presence, or absence, of motion in the plane normal (perpendicular) to the plane of the conveying surface.

Angular-pitch vibrating conveyor

In its simplest form, the angular-pitch vibrating conveyor consists of a trough with a mechanism to oscillate it. This type of conveyor can typically be either a "brute-force" type or the natural-frequency type. The majority of angular-pitch vibrating conveyors require vibration isolation to prevent imparting unwanted vibrations to the surrounding support structure. The typical operational frequencies of these conveyors are from 5 to 60 Hz, with common pitch angles from 10 to 45 deg. Typical pitch displacements can range from 0.03125 to 1.5 in.

A brute-force type vibrating conveyor is one that relies strictly on imparting a force to a mass to achieve an intended displacement. These are the least energy-efficient of the vibrating conveyors, but generally have a lower initial cost. This type of conveyor allows for speed (flow) adjustment during operation. Brute-force-style conveyors must be isolated from the surrounding structure and are generally shorter in length than other types.

The natural-frequency type vibrating conveyor utilizes the resonance frequency characteristics of a spring system to reduce power requirements, as well as the forces required to be introduced into the system to operate. These are the most energy-efficient of the angular-pitch vibrating conveyors. These types of conveyors can be either unbalanced (earth-anchored), frame-balanced (requires isolation from surrounding structure) or dynamically balanced (utilizing an equal opposing mass).

Natural-frequency vibrating conveyors employ a simple harmonic motion (that is, sinusoidal) directed along a line that slopes upward in the direction of travel. This line is called the line of action (Figure 1). This type of conveying action will stratify the particle sizes being conveyed, which makes them a good resource for screening out oversized and undersized particles from the conveyed material. The pitching action of these types of conveyors, however, can degrade fragile products.

Horizontal-differential motion conveyors

With horizontal differential-motion conveyors, the differential-velocity motion (having different mean velocities and peak accelerations through each half of a cycle) can, through differential friction, cause movement of the mass or object in the direction of the lower mean velocity of the conveyor trough. The line of action may be parallel to the conveying surface. The mass will slide along the surface in a series of sequences, as shown in Figure 2.

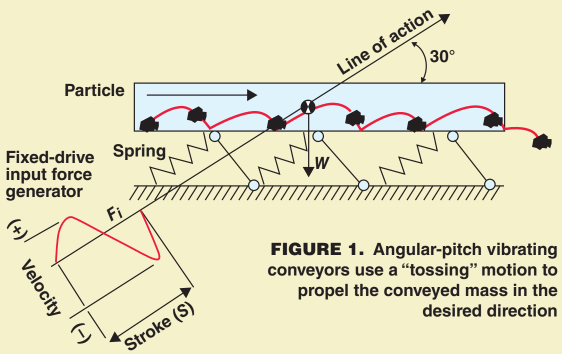


FIGURE 1. Angular-pitch vibrating conveyors use a "tossing" motion to propel the conveyed mass in the desired direction

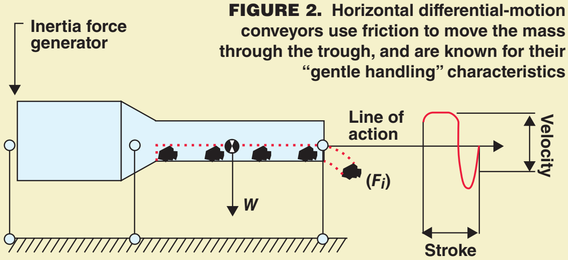


FIGURE 2. Horizontal differential-motion conveyors use friction to move the mass through the trough, and are known for their "gentle handling" characteristics

The horizontal differential-motion conveyor does not agitate or damage the product being conveyed. The horizontal linear motion of this type of conveyor will not mix or stratify the conveyed materials. Even though it is a friction-dependant type of conveyor, scuffing or marring of the materials is generally not observed over long conveying runs. These conveyors are known for their "gentle handling" characteristics.

Horizontal differential-motion conveyors do not rely on system resonance or frame-mounted reaction forces to operate. Operational frequencies generally fall into the 2.5 to 6 Hz operating range with displacements of 0.75 to 3.0 in., depending upon the application. Frequencies can be adjusted during operation to control the conveying velocity.

Horizontal differential-motion conveying systems are generally suspended using a pendulum-type support system (either above or inverted below the conveyor trough). Supports can be placed up to 20 ft apart and the conveying troughs can be in excess of 200 ft long. Inertial force generators (drives) can typically be placed at either end, above or below the conveying trough and can convey either uni-directionally or bi-directionally. These attributes make this type of conveying method very cost-effective for longer distances.

Determining conveyor type

The following is a set of questions that can help determine the best conveyor type for a specific product application:

- Is your product fragile, coated, dusty or agglomerated? → horizontal motion
- Are you moving product at a high travel rate? → natural frequency
- What is the conveying length (over 30-ft long)? → horizontal motion
- Do you need to convey uphill (0 to 5 deg)? → natural frequency
- Are wide temperature differences expected? → horizontal motion
- Is your product wet or sticky? → natural frequency
- Do you have heavy surges in your product flow? → horizontal motion
- Do you need to screen the product? → natural frequency
- Do you have restricted space for the material pan? → horizontal motion
- Are sanitation issues important to you? → horizontal motion
- Do you need frequent start-stops? → natural frequency
- Is pan wear and noise a concern? → horizontal motion
- Are wide-ranging variable speed or reversing modes needed? → horizontal motion
- Do you need to spread your product to uniformly feed a dryer or cooler? → natural frequency

Editor's note: Content for this edition of "Facts at your Fingertips" was provided by Triple/S Dynamics Inc. (Dallas, Tex.; www.sssdynamics.com).

Circle 18 on p. 56 or go to adlinks.che.com/45773-18

Technology Profile

Ethylene Production via Ethanol Dehydration

By Intratec Solutions

Ethylene is arguably the most important building block of the petrochemical industry, frequently produced via steam cracking of a range of petroleum-based feedstocks. Rising oil prices and concerns about global warming have motivated research into ethylene manufacture from renewable sources.

The "green" ethylene made from ethanol (for example, from corn, sugarcane or lignocellulosic biomass) represents a chemically identical alternative to its petrochemical equivalent, and can contribute to the overall reduction of greenhouse gas emissions.

Ethanol dehydration

The polymer-grade (PG) ethylene production via ethanol dehydration process depicted in the figure below was compiled based on a U.S. patent published by BP Chemicals (London, U.K.; www.bp.com; U.S. patent no. 8,426,664). Since 2008, BP has established more than ten patents on this subject.

Ethanol dehydration has an overall endothermic equilibrium. The ethylene yield is favored by higher temperatures, while lower temperatures favor production of diethyl ether (DEE). The major process steps are outlined below.

Treatment. Fresh ethanol is combined with the recycled ethanol and DEE from the ethylene column and sent to the aldehyde removal column, which removes the aldehydes that came from the fresh ethanol feed, as well as the aldehydes and C4 hydrocarbons generated in the reaction step.

Reaction. The bottom stream from the aldehyde removal column is sent to the feed vaporizer and superheater before being sent to the reactors. The process uses fixed-bed reactors with a heteropolyacid catalyst supported by silica. The product stream from reaction is cooled and sent to the purification section.

Purification. The reactor's outlet stream primarily consists of unreacted ethanol, water, ethylene and DEE. The stream is sent to a first distillation column to separate mainly the ethylene from the water. The ethylene-rich overhead stream is then compressed, dried and sent to an ethylene purification column. The bottom stream from the ethylene-water separation column is then sent to a dewatering column, to separate water. Streams containing mainly ethanol and DEE are recycled back to the treatment section.

Key research basis

The key information used as input to develop the synthesis of the process is presented below. The final process design was based on reasonable values from the ranges presented here. Since the technology is in its embryonic stages, and no commercial plant has been built using this concept thus far, the design depicted here is subject to changes.

Reactor temperature	200 to 250°C
Reactor pressure	10 to 28 bars abs
Ethanol conversion to ethylene (per pass)	20 to 60%
Feed ethanol water content	1 to 5 wt.%
Diethyl ether in reaction feed	50 to 85 wt.%
Catalyst-bed temperature profile	<10°C

- According to BP, the formation and recycling of DEE thermodynamically favor the separation of water, and result in higher ethylene selectivity
- Moderate reaction conversion and mild temperature and pressure conditions are used in order to improve the selectivity for the desired products.

Economic performance

An economic evaluation of the process was conducted based on data from the second quarter of 2012 with the U.S. Gulf Coast as the location. The following assumptions were assumed for the analysis:

- A 190,000-ton/yr chemical production unit (all equipment represented in the simplified flowsheet below)
- Storage capacity equal to 20 days of operation for ethanol and no storage for ethylene
- Outside battery limits (OSBL) units considered: steam boilers, cooling towers, propylene refrigeration system, control room and administrative buildings

The estimated capital investment (including total fixed investment, working capital and other capital expenses) to build an ethanol dehydration unit would be between $200 and $280 million, and the operating cost would be about $1,650/ton. Given that the petroleum-based ethylene sales price is lower than the green (via ethanol dehydration) ethylene cost of production, the green ethylene sales price must include a premium of more than 50% over petrochemically derived ethylene to make the venture economically feasible.

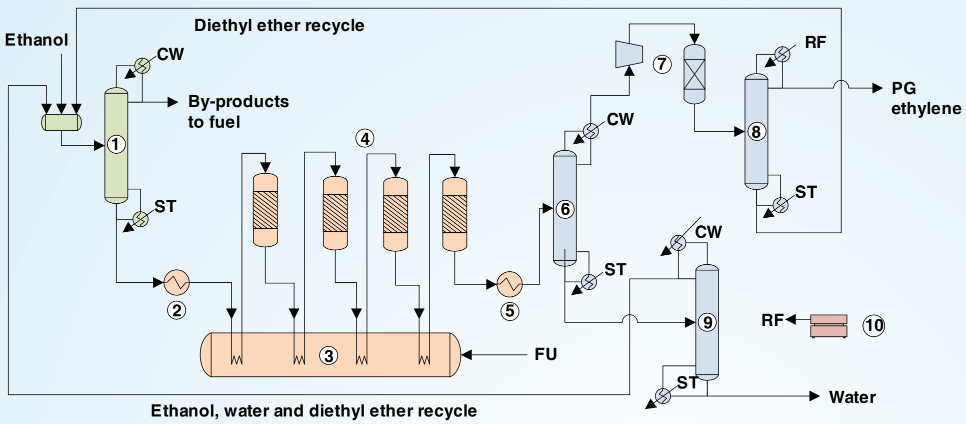
Research perspective

Strategic, financial and technical insights about this research into the ethanol dehydration process inlcude the following:

- Marketing and sales teams must find niche-market consumers willing to pay more for an environmentally friendly product (for example, plastic containers for the cosmetics industry)
- Since ethanol raw material prices are dictated by markets such as food and fuel, it may be an interesting consideration to control the entire supply chain through the integration of the ethanol dehydration unit with an ethanol production unit
- The published patents describe problems related to the temperature profile of the catalyst bed. Researchers must focus on developing a catalyst with improved tolerance to the temperature decrease inherent in the endothermic nature of the dehydration reaction. Higher conversion and higher selectivity for ethylene would minimize recycling loops and, consequently would reduce both capital and operating costs ■

Edited by Scott Jenkins

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



1) Aldehyde removal column
2) Feed vaporizer
3) Feed superheater
4) Dehydration reactors
5) Cooler
6) Ethylene-water column
7) Compressor and drying
8) Ethylene column
9) Dewatering column
10) Propylene refrigeration unit

FU Fuel
CW Cooling water
RF Refrigeration fluid
ST Steam

Solving Vessel Equations: A Better Way

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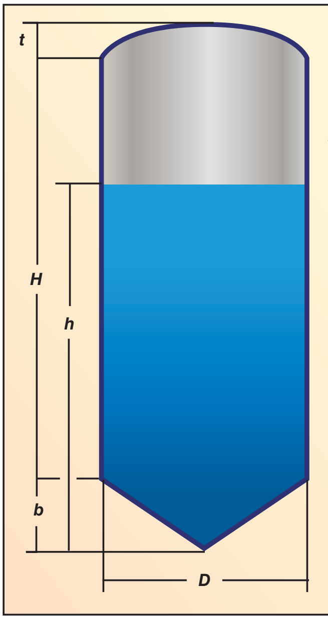
Irregularly shaped vessels present challenges for determining liquid volumes. New tools can help

Calculating the volume of a liquid in a vessel of a complex shape is a common task for chemical engineers. However, there are several difficulties associated with accurately carrying out this calculation.

In my own experience as a chemical engineer, I have become familiar with the complexities of calculations related to determining the volume of a liquid contained in a vessel with an irregular shape.

Precise volume-determination equations are readily available for common vessel shapes. But what if you are using a vessel that is a vertical cylinder with a hemispherical top and bottom? Or, what if you are working with a horizontal elliptical vessel with concave heads? No matter the type of vessel you are working with, chemical engineers need to account for the liquids within these irregular shapes to calculate the volume properly.



Volume of vertical cylindrical shell:

$V_c := \pi R^2 \cdot h_c$

where $R := \frac{D}{2}$

Shell diameter $D := 50$ in.
Shell height $H := 150$ in.
Liquid level $h := 150$ in.

Volume of conical bottom:

$V_b := \frac{\pi}{3} \cdot \left(\frac{R}{b}\right)^2 \cdot h_b^3$

Bottom height $b := 30$ in.

Volume of elliptical top:

$V_t := \frac{\pi}{3} \cdot \frac{R^2}{t^2} \cdot h_t \left(3t^2 - h_t^2\right)$

Top height $t := 10$ in.

Conditions:

$h_c :=$ if $(H+b \geq h) \wedge (h > b)$
  $h - b$
 else
  0

$h_t :=$ if $(h > (H+b))$
  $h - H - b$
 else
  0

$V :=$ if $(h \leq b)$
  V_b
 else
  if $h \leq (H + b)$
   $V_c + V_b$
  else
   $V_c + V_b + V_t$

$h_b :=$ if $(h < b)$
  h
 else
  b

FIGURE 1. Calculating the volume of a liquid in an irregularly shaped vessel involves combining equations for the various portions of the vessel, such as a cylinder portion, a conical portion and an elliptical portion, in this case

Vessel-calculation challenges

Let's begin with an example scenario. Suppose a chemical engineer works at a pharmaceutical facility that produces cough syrup. In that capacity, the engineer may have to prepare a solution in a 1,000-gal vessel or tank with an irregular shape. To prepare the proper concentration of cough syrup, he or she may need to add 50 pounds of an active pharmaceutical ingredient into sugar syrup.

Before adding anything to this liquid base to prepare the proper concentration, the exact fluid volume must be known. One option is to measure the volume using a meter pump, but this method will not produce an accurate result. The alternative is to verify the exact amount of liquid needed by calculating the volume of this irregularly shaped vessel based on the liquid level.

In this scenario, suppose that the vessel in question is a vertical cylindrical vessel comprised of a conical bottom and elliptical top. The elliptical portion of the vessel is partially filled with liquid, while the cylindrical and conical portions are fully filled (Figure 1). What should be the approach to calculating the portion that is partially filled?

To calculate the total volume, you need to combine the different equations — one for each of these three basic shapes of the vessel: the conical bottom, the elliptical top and the vertical cylinder.

At this point, two complexities arise. Engineers are forced to search through databases and manuals for the equations that are appropriate for the irregular parts of the tank, and then calculate the volume using some kind of calculation software. While many engineers favor Microsoft Excel as their calculation software of choice, keep in mind that the program was not specifically designed for entering complex equations. As a result, this process for calculating the volume of a particular vessel can be a time-consuming and inefficient process. Engineers cannot afford to waste time — they need reliable equations and quick calculations.

In a similar scenario (depicted in Figure 1), the author and colleagues first either found and verified, or derived equations, in some instances using integrals, for each shape involved. Glancing through a reliable en-

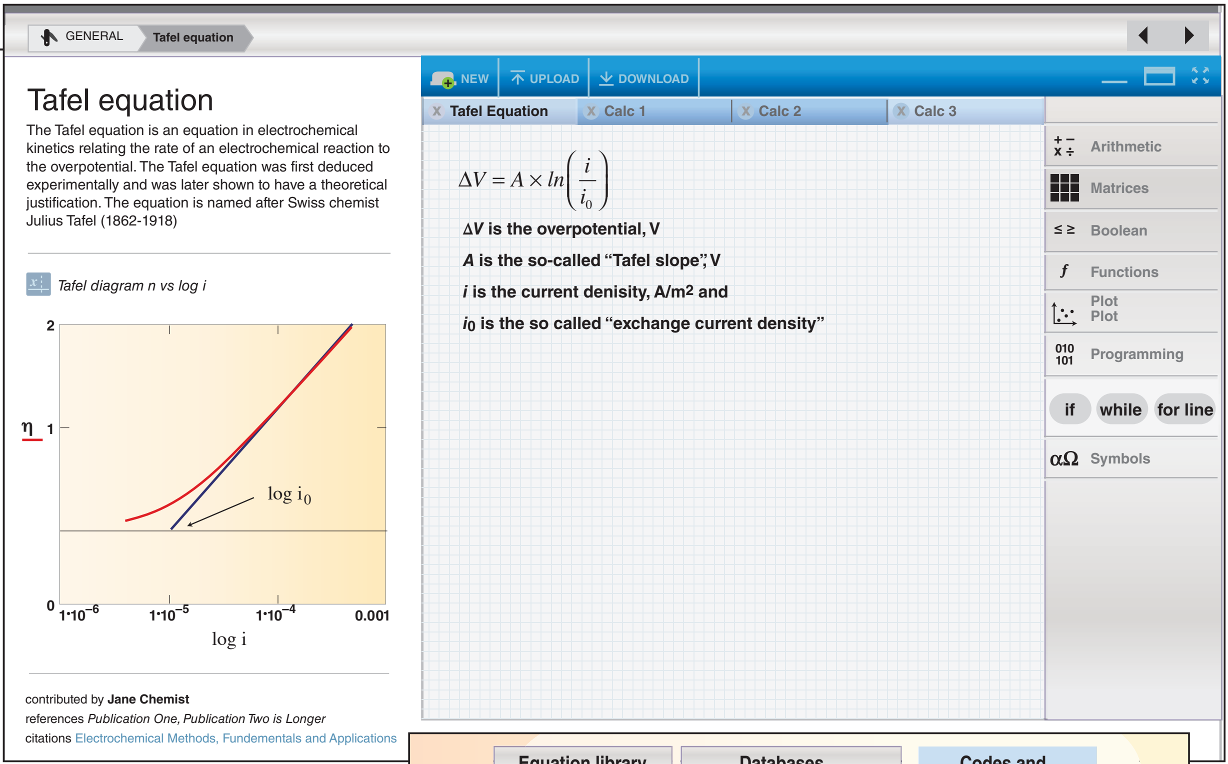


FIGURE 2. A Web-based equation library can help in vessel calculations

gineering book, such as Perry's Chemical Engineers' Handbook, revealed nothing useful for this problem.

We had better luck conducting Internet-based research, but it was not until poring through many search results that we came across the following article by Dan Jones — "Calculating Tank Volume" (http://www.webcalc.com.br/blog/Tank_Volume.pdf). Also see (*Chem. Eng.*, Sept. 2011, pp 55–63).

Using the equations provided in Jones' article for practical calculations proved to be a problem in itself. First, the equations had to be assembled in a sensible way to account for all the shapes containing liquid in the vessel. In addition, depending on the level of the liquid you are working with, there are different equations that have to be used.

Another common frustration for chemical engineers is that the data found online must be validated as well. Often with research conducted online, the reliability and validity of the the information found is not clear or defined. Checking the validity of the equations that are found can be complicated. To be sure that an equation is validated, engineers may need to recalculate everything from scratch — which we did

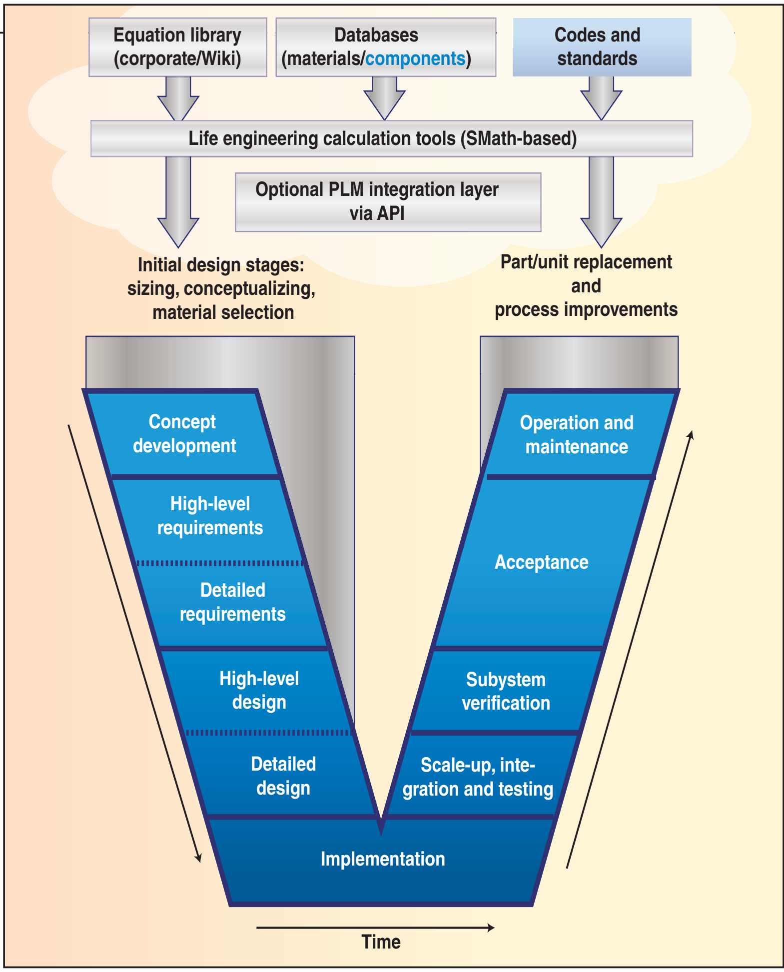
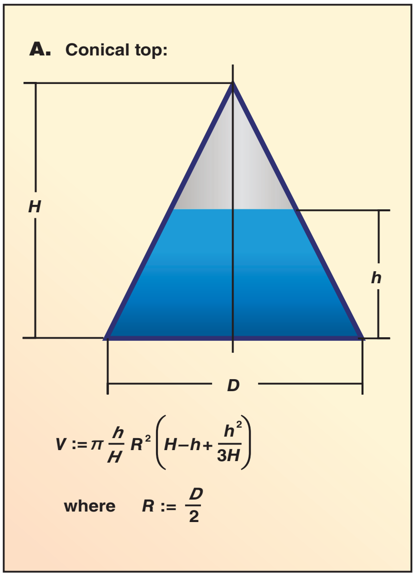
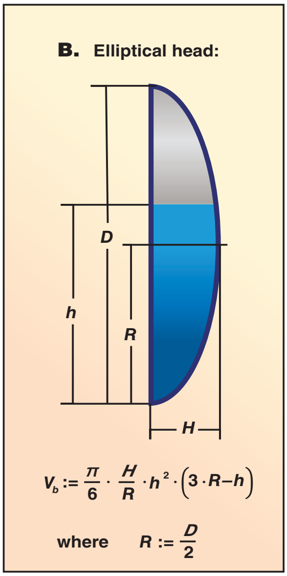
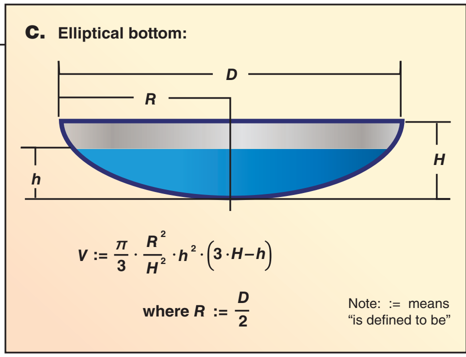


FIGURE 3. Cloud-based calculation tools can improve engineering workflow







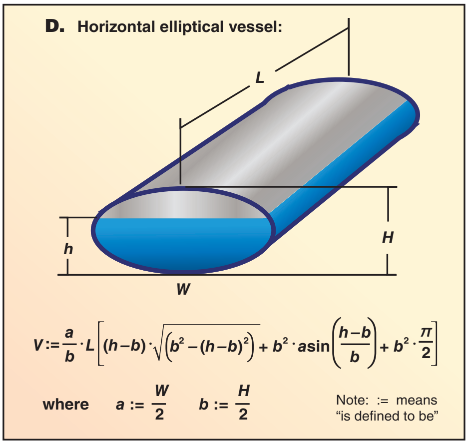


FIGURE 4. (A–H) Various standard shapes that can be combined include cylinders, cones, ellipsis and hemispherical. The diagrams and equations show some of the possible situations for volume measurement that engineers might face

in this case — and of course, it ended up costing us even more time.

Once we found and validated the equations and vessel dimensions, the next step was to use a calculation tool that is easy to integrate with the data. We first turned to Microsoft Excel, probably the most-often-used tool in many engineers' toolboxes. For most calculations and analyses, an Excel spreadsheet would suffice. Several generations of engineers now have grown up using Excel — it's a common, inexpensive software that is readily available on most desktops and laptops. In addition to its familiarity, it's relatively easy to input large amounts of data into Excel.

However, in this case of calculating volume in an irregularly shaped vessel, it was not. It became clear that it would become an exceedingly time-consuming process just to enter the equations and variables.

Other reasons why Excel was not the right calculation tool in this case is that programming is required with external data. Second, all calculations must be performed in a consistent system of units with conversion factors embedded in equations. This is because Excel does not automatically understand the units of measurement and does not support calculations in different unit systems unless additional programming is introduced. Third, we planned to create a browser-based application, but the Internet version of Excel has exhibited performance issues and is not highly rated by many users.

Beyond Excel, there are engineering calculation tools available such as PTC's (Needham, Mass.; www.ptc.com) Mathcad, which has automatic unit conversion and can check equations for mathematical errors. However, a browser version of Mathcad is not available, and that limits its usefulness in cloud-based applications.

SMath

To calculate the volume of a liquid in a vessel of a complex shape, a task that should take only minutes, we tested a tool that is readily available online and that could integrate our data. We found an engineering desktop calculation tool that is both powerful and distributed free of charge — SMath Studio (http://en.smath.info/forum/yaf_topics12_Download-SMath-Studio.aspx).

SMath has a browser version called SMath Live. While it is functionally similar to the desktop version, it needs further development. SMath, developed specifically for engineering calculations, is now used by thousands of engineers and engineering students around the world.

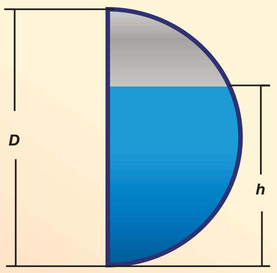
This tool consists of a powerful math engine core, user-friendly worksheet-based graphical user interface (GUI) and plug-ins — some of which are open source software — that connect the core with GUI. SMath has the following features:

- The ability to handle numeric and symbolic calculations
- Capabilities for 2-D and 3-D graphs
- Software versions designed for different platforms and operating systems
- Partial support of Mathcad files (*.xmcd)
- The ability to use mathematical units (either built-in or user defined)
- Multi-language worksheets
- Multi-language interface (28 languages)
- The capacity to use programming functions directly on the worksheet
- Infrastructure to support third-party plug-ins
- An auto-complete feature with description of all supported entries
- The ability to use the tool in collaboration (via server)
- Equation snippets

Improved volume calculations

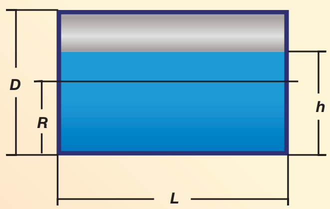
The tools chemical engineers have at their disposal are critical for main-

E. Hemispherical head:



$$V_b := \frac{\pi}{6} \cdot h^2 \cdot (1.5 \cdot D - h)$$

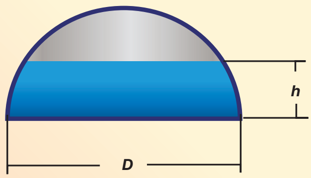
G. Horizontal cylinder:



$$V := L \cdot \left[R^2 \cdot \text{acos}\left(\frac{R-h}{R}\right) - (R-h) \cdot \sqrt{2 \cdot R \cdot h - h^2} \right]$$

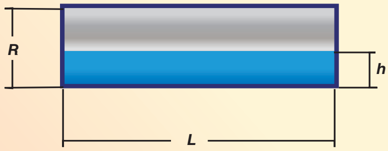
where $R := \frac{D}{2}$

F. Hemispherical top:



$$V := \frac{\pi}{3} \cdot \left(\frac{D^3}{4} - \left(\frac{D}{2} - h \right)^2 \cdot (D+h) \right)$$

H. Horizontal hemicylindtrical top:



$$V := L \cdot \left[0.5 \cdot \pi \cdot R^2 - R^2 \cdot \text{acos}\left(\frac{h}{R} \right) - h \cdot \sqrt{R^2 - h^2} \right]$$

taining high levels of productivity. Ideally, engineers should use tools that are seamless, can save time, and avoid costly errors in the workflow. One way to accomplish this is through cloud computing, where software programs and data that have traditionally resided on company servers are now located on a third party's remote servers and are accessed via the Web.

Cloud computing assures today's engineers quick and easy access to data from anywhere on a variety of devices. It also allows engineers to easily share data with their peers across the globe. Fortunately, as technology continues to move into the cloud, engineers will have more effective and reliable tools to integrate data, such as equations with calculation software, into their design and workflow.

Currently in the early stages of development, there is an engineering cloud-based productivity tool (Figure 2) comprising of SMath Live integrated with a searchable and browsable library of common engineering equations, including those for partially filled shapes, that could help you calculate liquid volume as a function of liquid level much faster than before. A chemical engineer could use this cloud-based product to find shapes and assemble them in any reasonable combination to calculate the volume of liquid in any partially filled vessel. Such a product will be useful when integrated into engineering workflow as an early-stage design tool. The stages of a typical engineering workflow where this tool can be integrated can be seen in Figure 3.

This type of Web-based product would enable users to find and select equations for various shapes and then assemble them like Lego blocks onto an SMath Live worksheet. If you are working with any unusually shaped shells, bottoms or heads, you can build any vessel from them using smaller pieces (Figure 4). You can continue to build up to more complex shapes and calculate the volume of the entire shape or the volume of liquid in partially filled shape. The same approach could be used for calculating the volume of dry particulates, suspensions and so on.

Initial results are encouraging and can be seen in Figure 1, which shows an example of a calculation for a vertical cylindrical vessel with conical bottom and elliptical top. This example was assembled from calculations for three basic shapes: cone bottom, elliptical top and vertical cylinder. Each calculation contains limiting conditions and validation routines, as well as graphic representation of a shape. These conditions and validation routines are easily adoptable for the vessel shown in the example.

A prototype of this cloud-based calculation tool is now underway. We believe that the future of engineering will be characterized by tools that integrate data and calculation software and are available in the cloud. Development and deployment of these sophisticated tools will be critical for maintaining high levels of engineering productivity in the chemical industry. ■

Edited by Scott Jenkins

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Understanding FDI

A concise explanation of Field Device Integration (FDI) Technology, and how new FDI standards will help make connecting easier

Martin Zielinski
FDI Cooperation, LLC

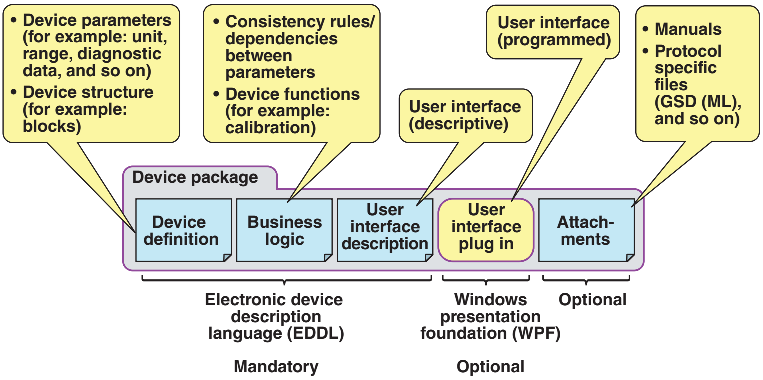

FIGURE 1. The core of FDI Technology is the FDI Device Package

With the advent of smart or intelligent field devices, a wealth of digital information has become available. However, what does the host system do with these data? The field device transmits a bucket of bits to the host system. How are these data converted into information that a human can interpret? Where is the information displayed? Should the information be stored as persistent data?

These questions are answered via a digital integration technology. Using an integration technology, a field device supplier can tell the host the answer to these questions. Field Device Integration (FDI) is intended to be a single integration technology for the process automation industry. It combines the best of what are available with today's technologies: Electronic Devices Description Language (EDDL) and Field Device Tool (FDT) technology.

The need for FDI

Why is FDI being developed when there are existing digital integration technologies? The answer is twofold. First, with two different integration technologies, users frequently have much more work implementing and maintaining their automation systems and asset management tools. Second, there are significant differences in how the digital integration technologies are implemented and what capabilities they support between different process-control and asset-management hosts, or even between different revisions of a single manufacturer's host.

Due to these differences, manufacturers are forced to support multiple digital-integration technologies for each device, and frequently multiple versions of each technology because of these host implementation differences.The net result is the manufacturer may need to develop multiple EDDL- and FDT-based solutions for each device revision and protocol. End users need to understand and implement those solutions that are appropriate for each of their specific host environments. These factors increase costs for both end users and device manufacturers. These issues are not isolated to specialty measurements, but affect common ones like pressure and temperature as well. While these issues are not insurmountable, they are a source of frustration and cost for both end users and suppliers. FDI is intended to minimize these frustrations.

How will FDI help? Globally leading control system and device manufacturers, such as ABB, Emerson Process Management, Endress+Hauser, Honeywell, Invensys, Siemens and Yokogawa, along with the major associations FDT Group, Fieldbus Foundation, HART Communication Foundation, OPC Foundation, Profibus & Profinet International, have collectively recognized the issues that end users face. Together, they are supporting and driving forward the development of an integration technology that combines the advantages of FDT technology with those of EDDL in a single, scalable solution. FDI takes account of the various tasks over the entire lifecycle for both simple and the most complex devices, including configuration, commissioning, diagnosis and calibration.

FDI basics

The core of FDI Technology is the scalable FDI Device Package (Figure 1). The FDI Device Package is a collection of files: the Device Definition (Electronic Device Description; EDD), Business Logic (BL) and User Interface Description (UID). It is based on Electronic Device Description Language (IEC 61804-3). The optional User Interface Plug-in (UIP) offers the advantages of freely programmable user interfaces familiar from FDT Technology, based on Windows Presentation Foundation (WPF). The device manufacturers define, via the FDI Device Package, which data, functions and user interfaces are stored on the FDI Server.

EDD. The Electronic Device Definition describes the field device data and the internal structure (for instance, blocks).

BL. The Business Logic primarily en-

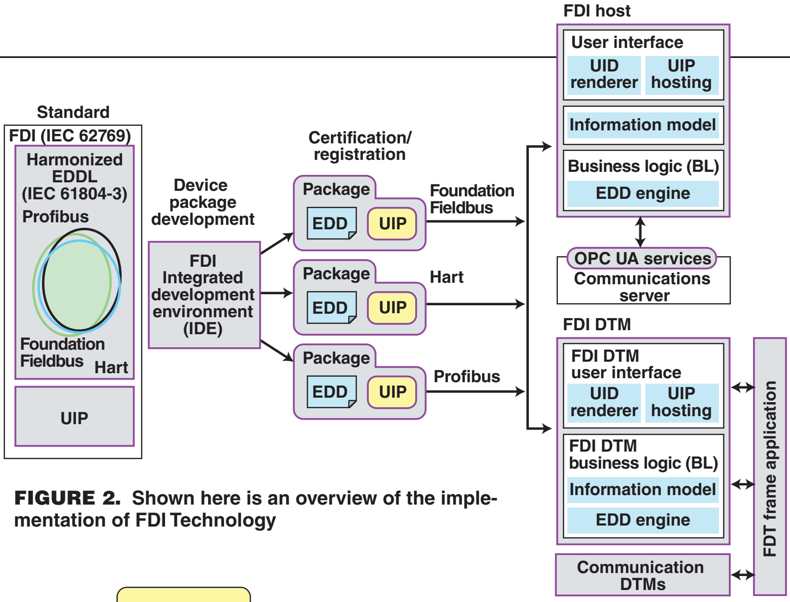

FIGURE 2. Shown here is an overview of the implementation of FDI Technology

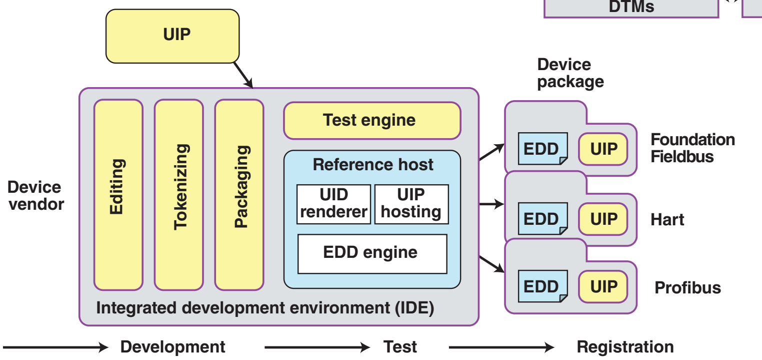

FIGURE 3. Integrated Development Environment (IDE) is the means for creating an EDD for a device

sures that the device data remain consistent, for example, the data are refreshed when the measurement units are changed. Dynamic dependencies, in particular, play a part here. Only the options or ranges are displayed that depend on prior selection of other settings, for example, only temperature units are shown, if a temperature sensor is chosen.

UID. The User Interface Description is a text-based means to convey the way in which parameters are to be displayed. The "look and feel" of the host system is preserved, while the display relationship of parameters is maintained, for instance, the zero and span of the range are shown on the same display and in close proximity to each other.

UIP. The User Interface Plug-in is a software module that executes a unique function or diagnostic with its own user interface. Product documentation, protocol-specific files, such as Profibus GSDs (general station descriptions) or Foundation fieldbus CFFs (common file formats), and so on, can be added to the FDI Device Package as attachments. FDI has defined a single, protocol-independent encoded-file format for the EDD part of the FDI Device Package.

Harmonization

Another important aspect of the FDI Project is the harmonization of EDDL across the HART, Foundation fieldbus, Profibus and Profinet protocols. For largely historical reasons, different language constructs evolved in the corresponding organizations. Being independent organizations, there was no reason or motivation for the different organizations to collaborate on changes to EDDL. For device suppliers, this means learning a variant of EDDL for each communication protocol. This leads to unnecessary complexity in the creating, testing and maintenance of an EDD.

In the FDI Project these variants are minimized. This leads to the creation of multiprotocol FDI Device Package development tools (FDI Integrated Development Environment), and uniform host components, such as EDD Engine (interpreter) and the client-side components UID Renderer and UIP Hosting. The result is sustainable strengthening of the key factors of interoperability and quality. At the same time, complexity is reduced for suppliers, communication foundations and end users.

To be clear, the Foundation fieldbus, HART, Profibus PA and Profibus DP protocols are different. By necessity, there are specific features for each protocol in EDDL and consequently in the FDI Device Package. FDI is a digital integration technology and describes the unique device and its protocol features. Let's look at the Integrated Development Environment (IDE; Figure 2) in a bit more detail.

IDE

The creation of an EDD for a device is straightforward (Figure 3). Using the text-based syntax structure of EDDL, the device developer defines the device and describes how the parameters are to be displayed on the host system. Using the Business Logic features the developer describes the dynamic dependencies among the parameters. For example, if he or she is describing a pressure transmitter, he or she would specify that only pressure units appear in the drop-down menu for the selection of units. With the help of the IDE editor, his or her text-based syntax is checked and converted into an FDI-encoded file format by means of "tokenizing" (the binary coding of an EDD).

The UIP is an optional software application. If the developer chooses to enhance the Device Package by adding this App (application), it would be developed using Visual Studio. A common attachment in a Device Package would be the product manual in the Portable Document Format (PDF). The encoded EDD, the UIP and the attachments would then be combined to form an FDI Device Package. Since the communication protocols are different, the Device Package will be created for a specific communication protocol.

The next step is to test the FDI Device Package. Within the IDE there is a Reference Host and a Test Engine.

The Reference Host is a runtime environment that exercises the FDI Device Packages for debugging purposes. It will run the Device Package against all of the test cases contained in the Test Engine. These test cases are the same as those that will be used in the registration process of the respective foundation. In one sense, these are artificial test cases. They are designed to force errors to occur with the intent of creating a fault-tolerant FDI Device Package. It should be pointed out that the UIP will be tested in a manner that verifies the software services of FDT2 supported by FDI. It does not verify the App operation. It verifies that the interface is being used properly. The developer will continue this iterative process of testing and debugging until he or she is satisfied with the results.

The final step is to register the FDI Device Package and the actual device hardware with one of the communication protocol foundations. For a given device type with optional communication interfaces for HART, Foundation Fieldbus (FF), or Profibus PA, such as a pressure transmitter, there will always be a corresponding HART FDI Device Package, an FF FDI Device Package, or a Profibus PA FDI Device Package. The advantage of the FDI technology is in its uniformity. Profibus DP devices will also be registered using this same process. FDI will make the creation, maintenance and host integration of a Device Package more straightforward.

What about the host system? This is where the cooperation with the FDT Group comes into play. The absolute goal of the FDI Project is that an FDI Device Package must be read by any host (Figure 4). It is a supplier's choice if the host is native EDDL, FDI or FDT2 based. The host could be device management software as part of a process-control or asset-management system, a device configuration tool on a laptop or a handheld field communicator. The FDI architecture allows for different kinds of host implementations including an FDT-Technology-based host system that ensures interoperability with FDT-based hosts. In any case, the host always supports the FDI Device Package and delivers the full functionality of the FDI Device Package.

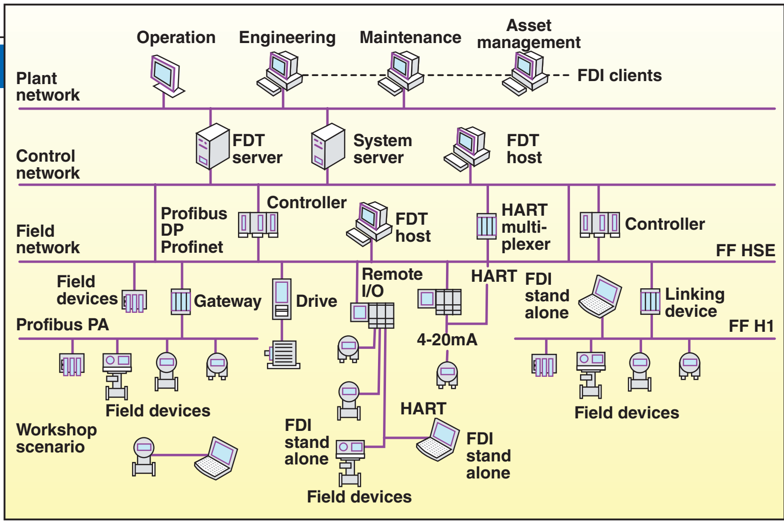

FIGURE 4. Host Systems are used in various applications

This goal is accomplished in two parts. FDI will make available to all host suppliers common software components to interpret, display and execute the contents of a Device Package. In addition, there will be a rigorous host registration test to insure uniform implementation of the common software components. The interpreter components available today are only for specific protocols and differ significantly in their functional capabilities and behavior toward the host system.

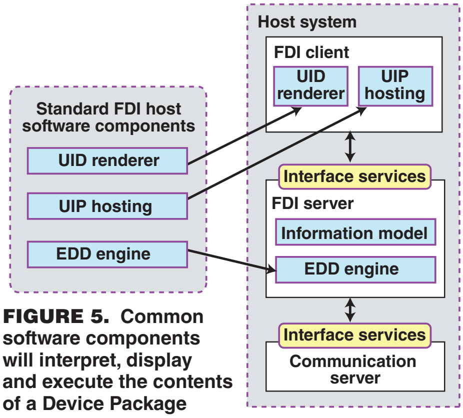

FIGURE 5. Common software components will interpret, display and execute the contents of a Device Package

FDI will develop uniform, multiprotocol standard FDI host components (Figure 5). EDD Engine (interpreter), UID Renderer (display) and UIP Hosting components (execution of the optional app) ensure that an FDI Device Package behaves in the same way on different systems. In accordance with IEC 61804-3, the EDD Engine supports the entire language scope of EDDL in a multiprotocol manner, and is backward compatible with existing EDD formats. This means that future system manufacturers no longer need to integrate three interpreter components, but only one. This not only saves time and effort, but also contributes to improving the quality and interoperability.

Host testing

Of necessity, a large part of the host system testing is accomplished manually, rather than being automated. The host under test (Figure 6) imports a Reference FDI Device Package for a specific communication protocol. This Reference Package is artificial in the sense that it is designed to exercise all FDI Device Package features specified for a specific communication protocol. The concept is that for a given communication protocol, the host should not only support all specified FDI features, but the features should be supported uniformly on different hosts of the same type. It is understood that the capabilities of a handheld communicator are different that those of a control system.

The benefits

FDI combines the tried-and-tested concepts of both EDDL and FDT Technology and thus provides benefits for all parties; suppliers and end-users alike.

For control-system manufacturers, FDI has specified a client-server architecture as an option. The communication between client and server is

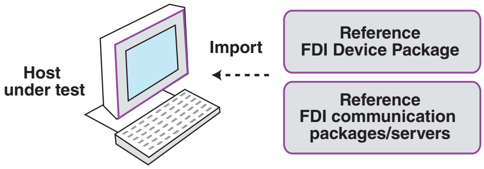

FIGURE 6. A host under test imports a Reference FDI Device Package for a specific communication protocol

based on OPC-UA, an international standard for automation solutions. This client-server architecture simplifies the use of device data and functions in distributed control systems. In addition, transparent access to device data and functions facilitates the integration of other applications [for example, connection of manufacturing execution systems (MES)]. Other benefits are clear: the central management of data prevents inconsistencies and the automatic loading of user interfaces by the client means client-side installation is no longer required.

For device suppliers, FDI reduces effort and saves costs because only one FDI Device Package has to be created for one device type, instead of the current EDDL- and DTM-based device package. Another advantage for suppliers is the scalability of the FDI Device Package. Simple devices get along with a simple-device package. By their nature, complex devices require a more-comprehensive device package.

An integrated development environment and standard host software components ensure interoperability and cost-efficient development of FDI Device Packages and host systems.

For the end-user, the main benefit of FDI lies in the standardized integration of field devices through a future-proof standard that ensures unrestricted interoperability of device packages from a wide variety of device manufacturers with FDI systems (FDI hosts) from a wide variety of control system manufacturers.

FDI is the underlying technology that is the means to achieve easy integration of digital information into host systems. ■

Edited by Gerald Ondrey

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Compliant Remote I/Os

NE 107 compliance for remote I/Os means proactive diagnostics for more efficient maintenance

FIGURE 1. The NE 107 recommendation suggests standardized and easily understandable color and symbol conventions for status displays

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Process sensors and actuators provide a wealth of information about their status. The Namur recommendation NE 107 that proposes standardized, easily understandable status indicators was issued by the International User Association for Automation in Process Industries (Namur; Leverkusen, Germany; www.namur.de), in an effort to enable plant operators to check the current condition of their field devices quickly and easily. NE 107 helps to structure such data in a concise manner by establishing distinct symbols and color codes.

Remote I/O (input/output) systems also generate messages and alarms that can provide helpful information for operation and maintenance. From a user's perspective, an implementation of the Namur recommendation for this technology was sorely missing until recently.

However, new remote I/O solutions now display important data on location at the module in a differentiated and concise manner according to NE 107. In addition, further alarm and message options also enable efficient information display on higher automation levels. Finally, thanks to integrated wear detection, select remote I/O systems even empower users to establish proactive or opportunity-based maintenance routines that are safer, more economic and more efficient than before. This article looks at these recent developments.

Background

The main purpose of diagnostic data gathered from field devices in modern process plants is to avoid production downtimes, since any standstill is almost certain to cause great economic loss. In order to facilitate a particularly efficient solution to that end, Namur published its recommendation NE 107 in 2007. This document not only emphasizes that all information must be reliable and available at all times, but also stipulates that diagnostics must be reported in a specific shape and form, irrespective of their particular origin and context, in order to make it as easy as possible for operators to determine and initiate proper reactions.

Moreover, non-essential information for the application in question should be screened out to ensure that no extra data might detract attention from where essential data are needed. In effect, this means that displays must be freely configurable: select information must be shown or withheld depending on the task at hand and the level where those data are presented, since information requirements are different for the person receiving them. For instance, requirements differ for users in the field, operators in process control rooms or supervisors responsible for asset management. On the other hand, no matter whether an extensive or minute subset of data is displayed, a certain standardization should provide clarity across the board for all mentioned user scenarios — and more.

The recommendation suggests color and symbol conventions for status signals to enable operators to quickly and easily grasp five specified conditions (Figure 1). A green display stands for a valid process signal in regular operation. Blue signifies that maintenance is required, though the signal remains valid. Yellow should alert users that a signal is out of specification. Temporarily invalid signals during functional checks feature an orange tint. Finally, red marks indicate invalid signals in cases of malfunctions.

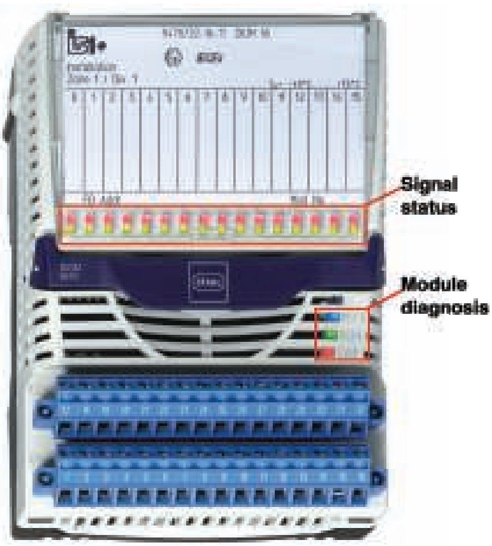

FIGURE 2. This commercial remote I/O module provide onsite operators with basic information through NE 107 and NE 044-oriented channel and device status LEDs

Remote I/O technology

The adaptation of this scheme has been a gradual process. In the years since the introduction of the recommendation, NE 107 has been partly implemented in process control systems, and widely in asset management systems. Many modern fieldbus devices for Profibus PA or Foundation

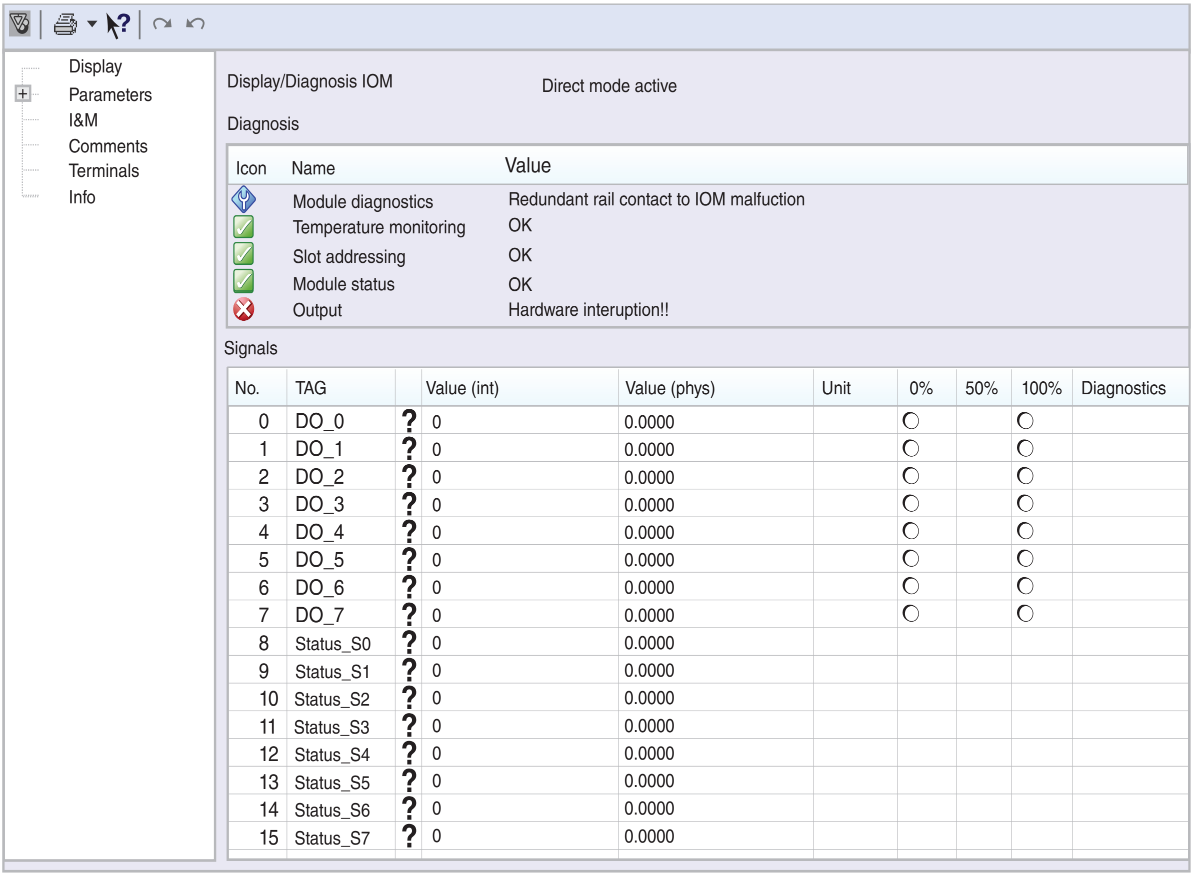

FIGURE 3. Via Device Type Manager (DTM), diagnostic data from field devices can be integrated, for example, into asset management systems in compliance with NE 107

Fieldbus (FF) H1 also already comply with Namur's recommendation, or will do so shortly. Implementations are due to follow suit or are already pending for several other fieldbus systems, including ProfiNet, FF HSE / F-ROM, and HART. However, until very recently, no remote I/O solutions that observe the recommended scheme had been generally available.

Remote I/O systems were first introduced about 25 years ago. This technology was conceived as a cost-efficient and flexible new solution for data acquisition in process plants (see The Benefits of Remote I/O and Fieldbus, *Chem. Eng.* September 2000, pp. 64-I&C-1–4). This was particularly crucial for hazardous areas, where explosion protection measures for all systems and components are generally indispensable, but inevitably add to the cost of equipment. Until the 1980s, and at many sites well into the 1990s, conventional point-to-point lines were deployed from each and every field device to a controller at a considerable distance. Every one of these individual connections carried an analog 4–20-mA signal. That inefficient setup was dispensed with, as remote I/O modules picked up signals via short lines from a few field devices in their vicinity, and then passed on all the information gathered via digital data transmission. In effect, this alternative did away with a huge number of lengthy dedicated wires. Moreover, state-of-the-art remote I/O technology now allows users to universally link both conventional and HART-compatible field devices in Zone 1 areas of a plant via digital communication to a control system on a higher automation level.

Balancing earlier standards

Despite the technical advantages and great cost-cutting potential, it took more than a decade for remote I/O technology to broadly catch on in the chemical process industries. At the time of writing, however, these systems are now very well established. They are not only already operating in countless process plants, but also still have an edge over all-digital, full-scale fieldbus installations in many newly devised projects throughout the world.

With regards to Namur NE 107, however, it is imperative for field devices and remote I/Os that a display design, which complies with this new recommendation, remain compatible with existing worldwide practices and standards (Figure 2). Especially yellow and orange (as well as white) light-emitting diodes (LEDs) are already used to display the switching status of devices, as suggested by the earlier NE 044 recommendation. Signal-related yellow LEDs for displaying the switching status should therefore be kept as-is in systems implementing NE 107.

Remote I/O modules should have per-channel diodes, namely a yellow LED for digital I/O signals and a red LED for inputs and outputs that flashes as proposed in NE 044 in case of line errors.

Another sensible feature would be a separate LED block for device-related information fitted with a green overall status LED, a red error LED, and a blue maintenance LED. The latter should use a steady light to alert operators whenever a replacement is necessary as a result of damage or wear. Flashing blue should be used to indicate that a module is no longer operating within specification, giving maintenance personnel a chance to take preventive or corrective measures before an actual failure comes to pass. Besides activating this blue LED, the module should also signal required maintenance by sending out a diagnostic "telegram." At a higher level, a distributed control system (DCS) or asset management software can then process such information as needed — that is, analyze it and integrate it via Device Type Manager (DTM), in compliance with NE 107 (Figure 3).

Proactive maintenance

Besides NE 107-oriented LED displays, state-of-the-art remote I/O modules should also feature an integrated wear-detection capability. During operation, such a system ought to continuously measure all relevant module parameters, such as ambient temperature, system load, and switch on/off cycles. Depending on these conditions, the realistic lifespan in the context of the actual application should then be calculated.

An NE 107-oriented monitoring function can notify users in time — for instance twelve months in advance — about the imminent end of life of a module. In most cases, users will then be able to exchange that module without urgency at the next convenient opportunity. This will significantly reduce unscheduled service assignments for operators and maintenance personnel, including the associated extra costs.

A detailed diagnosis will, of course, also help users avoid unnecessary exchanges of modules according to a fixed cycle. Through NE 107-compliant remote I/O, users stand to benefit from the advantages of the Namur recommendations in most automation environments, and this is much more extensive than previously possible.

Unfortunately the NE 107 still cannot be expected to be universally supported in the future, especially not by all standard fieldbus systems. Notably, there are no plans to implement the recommendation for the widely used Profibus DP. For this fieldbus, some remote I/O systems now at least provide a partial solution for cyclical transfer of process values similar to Profibus PA or Foundation Fieldbus H1. Just like fieldbus technology, these current systems use a status bit in order to report for each channel whether the signal is within specifications or faulty. This feature for Profibus DP anticipates the status information that is to come at a later time in a similar form for ProfiNet, though with a width of one byte instead of merely one bit. ■

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Vapor Depressurization: Concept and Implementation

When carrying out depressurization calculations, special attention is needed for critical equipment and systems such as rotating equipment, columns and reactors

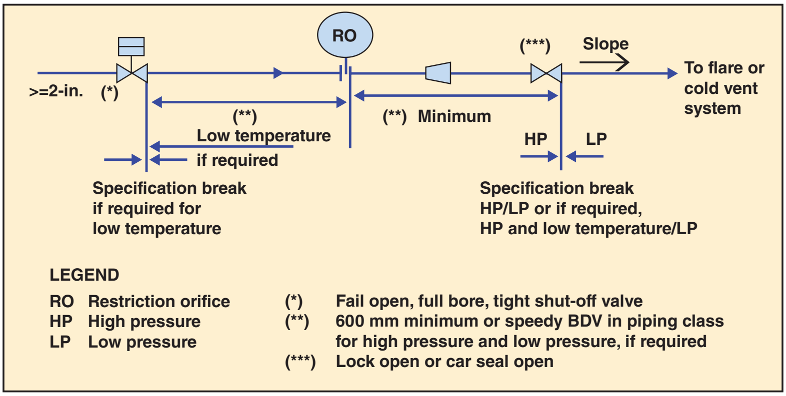

FIGURE 1. Shown here is a typical arrangement for a blowdown system. It consists of an on/off valve, a restriction orifice (RO) and a block valve

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During process operations, elevated pressure inside of isolated zones within a process or system can be rapidly reduced by the release of gas and vapor to a dedicated blowdown network. Analysis can be carried out to determine whether a given pressure-relief device will provide sufficient protection from potential vessel rupture for an unwetted-wall vessel or a vessel containing a high-boiling-point liquid.

When a pressure-relief valve alone is not adequate, additional protective measures must also be considered. These include, among others, the use of water sprays, depressurizing systems, fireproofing, earth-covered storage and diversion walls.

More often, depressurizing systems are used to reduce the failure potential for scenarios that may involve potential overheating (that is, a risk of fire). For instance, when the temperature of a metal is increased due to exposure to fire or exothermic or runaway process reactions, a stress rupture can develop. This can occur even though the system pressure has not necessarily exceeded the maximum allowable level.

Figure 1 shows a typical arrangement for blowdown system. It consists of an on/off valve, a restriction orifice (RO) and a block valve.

In this case, a depressurizing system can help to reduce internal stress, thereby extending the life of the vessel at a given temperature and reducing the risk of failure. To be effective, such a system must depressurize the vessel such that the reduced internal pressure is maintained below the critical value that will lead to vessel rupture.

The ability to depressurize the leak source can also help reduce the duration and severity of the incident, because a vessel rupture can literally "add fuel to the fire." In general, the depressurization rates should be maximized within the total flare system capacity — that is, the sum of all required simultaneous depressurization and relief rates should be close to, or equal to, the flare system capacity.

Requirements

To identify systems that need depressurization, the criteria described below can be used. However, most of the time it is either the company's past experience, or the project- or client-specific requirements, that dictate the system design.

- The trapped system inventory of hydrocarbons is above a minimum value (for instance, 2 tons of butane to 15 tons of butane and so on)
- The system contains toxic gases (such as H_2S)
- The system contains any flammable liquid above its autoignition temperature
- The units represent high-pressure sections of hydroprocessing units, such as the catalytic reformer, hydrotreater or others (these typically have depressurization systems)
- The potential for runaway reactions exists
- The compressor circuit can be isolated by shutdown valves
- For the hydrocarbon section, the following correlation between pressure and volume is satisfied:

$P \times V > 100$, with $P > 6.9$ barg

where P is the maximum operating pressure in barg and V is the volume inventory in cubic meters. Depressurization facilities may not be required when the system design pressure is lower than 6.9 barg.

- Depressurization to reduce the potential risk of fire scenarios should be considered for large equipment operating at a gage pressure of

1,700 kPa (approximately 250 psi) or higher

Time, special considerations

As per API 521 [*1*], equipment pressure shall be reduced from its initial conditions to a level equivalent to 50% of the vessel's design pressure within approximately 15 min.

This criterion is based on the vessel-wall temperature versus the stress that is required to rupture, and applies generally to carbon-steel vessels with a wall thickness of 25.4 mm (1 in.) or more. Vessels with thinner walls generally require a somewhat faster depressurizing rate. The required rate depends on the metallurgy of the vessel, the thickness and initial temperature of the vessel wall and the rate of heat input.

Other criteria for defining depressurizing time (often based on the project or company philosophy) are:

- 2 min per 3 mm of vessel thickness with a minimum of 6 min and a maximum of 15 min
- For some equipment, such as molecular sieves, reactors and more, the vendors specify a rate (for instance, 50–100 psi/min) to protect equipment integrity
- The depressurization of a system containing rotating equipment may also require special consideration. Depressurizing may be required in much less than 15 min in the event of a loss of seal-oil pressure. In such cases, the rotating equipment vendor may state the maximum time for depressurizing
- Columns may initially have very high vapor flowrates when depressurization starts. The column's vapor rate may be limiting based on the maximum vapor flowrate allowed by the vendor. In such cases, controlled depressurization shall be carried out

Note: Vapor depressurizing may be impractical when the vessel operating pressure is less than 8 bara, because for these circumstances, the associated valves and piping can become unreasonably large and costly.

Sizing

The sizing of the vapor-depressurization equipment for a system requires the calculation of flowrate and minimum-design metal temperature, upstream line sizing and downstream line sizing. The calculation of flowrate and minimum-design metal temperature can be carried out using the method described in API 521 and using simulation software (such as HYSYS or PRO II). It is quite possible that the governing case for the flowrate is the fire case, whereas the governing case for the minimum design metal temperature is another operating case. In such circumstances, separate calculations shall be performed to calculate the flowrate and the minimum-design metal temperature.

If both calculations are to be performed, then the governing flowrate (hence, the restriction orifice size) is first calculated with a given time constraint (for instance, 15 minutes with final pressure of 6.9 barg, or 50% of operating pressure; see the Box on p. 45 for the initial condition). The minimum-design metal temperature is then calculated by using the calculated restriction-orifice size, and by reducing the pressure to a minimum flare back pressure (without any time constraint). For instance, it can take more than 15 minutes (even 1 to 2 hours), with a given restriction orifice size to reach the final pressure as the minimum flare back pressure.

Where a preliminary determination of the depressurizing rate is required, the following equation can be used:

$$W_1 = \frac{NM}{t}\ln\left(\frac{P_1}{P_2}\right) \quad (1)$$

where:

W_1 = the initial depressuring rate, kg/min
N = the initial moles of vapor in the system
M = the molecular weight of vapor, kg/kmol
t = time, min
P_1 = initial upstream pressure, bara
P_2 = final upstream pressure, bara

Note: Any consistent set of units can be used.

This equation provides good results for vapor-only systems — that is, systems where the vapor generated from liquid flash or fire accounts for a small proportion of the total vapor; for example, the depressurization of a compressor system for process reasons.

For other systems, a contingency of between 20–100% should be applied to the calculated rate, to allow for uncertainties (for instance, vapor molecular weight changes that may result from liquid flash).

It should be noted that Equation (1) is valid only for systems where the flowrate from the depressurization calculations is critical for the duration

GENERAL CONSIDERATIONS

- When depressurization of many units is required, it should be done sequentially based on criticality and safety considerations. Such an approach can prevent the oversizing of the flare system
- Depressurization is normally done manually, either from the field or from a remote location. However, in unattended operation, such systems can be actuated automatically by a signal from the emergency shutdown system, or initiated by a fire- or gas-detection system
- If there are many different compositions and conditions, the worst conditions are the ones which, in the case of depressurization, will generate the maximum volumetric flare load
- For the wetted fire case, generally the lowest liquid-density condition provides the highest peak-capacity load. Meanwhile, in the case of gas expansion, all operating cases shall be considered in order to evaluate both the maximum volume (for hydraulic calculations) and the mass (designing for flare loads)
- It should be ensured that common mode failure (such as loss of instrument air or electrical failure) cannot cause all the depressurizing valves to open simultaneously; otherwise the flare system must be able to accommodate this possibility. To avoid simultaneous opening of depressurization valves and ensure safety, separate air and power supply systems are usually warranted for each section
- Within a fire zone, all depressurizing valves can open simultaneously
- It should be noted that depressuring facilities are not typically provided for bulk storage of volatile liquids (such as liquefied petroleum gas, LPG), as the large inventories would lead to excessively large relief systems. Instead, protection is normally provided by water-deluge systems, which cool the metal wall to maintain a temperature below that at which a stress rupture may occur
- When depressurizing results in temperatures lower than the minimum design temperature for full pressure, depressurization shall not be done until the system warms up to the minimum design temperature for full pressure ❏

INITIAL CONDITIONS

The initial conditions for the problem discussed here can be summarized as:

- Operating pressure equal to the design pressure is assumed to be the starting point, unless the design pressure is much higher (for instance, greater than 10% above the operating pressure). In this case, the maximum operating pressure or PSHH (pressure switch high high) must be selected to avoid unnecessary oversizing of the blowdown valve. For a compressor system, the initial pressure is the settleout pressure.
- Temperature is equal to the maximum operating temperature (it is assumed that heat exchangers are stopped). If the intention is to determine the minimum-design metal temperature, the initial temperature is the minimum operating temperature or the minimum ambient temperature, whichever is less.
- Liquid level is equal to normal liquid level for vessels with auto-level control, and high liquid level for vessels with on/off control.

For piping systems only, the liquid level corresponds to the piping hold up for piping. ❑

EXAMPLE

Consider the example of a compressor system that has the following conditions:

Settleout pressure (P_1)	=	63.2 bara
Initial temperature	=	20°C
Total system volume	=	487 m^3
Initial total moles (N)	=	1,520
Molecular weight (M)	=	19.15
Final pressure (P_2)	=	7.51 bara
Depressurization time (t)	=	15 min

Depressurization rate from Equation (1)

$$W_1 = 1{,}520 \times 19.15/15 \times \ln(63.2/7.5) = 4136 \text{ kg/min} = 248{,}163 \text{ kg/h}$$

Result from HYSYS simulation = 229,114 kg/h

It can be seen that the results obtained from both calculations are very close.

of depressurization. It also assumes that temperature, molecular weight and compressibility are constant throughout this period.

Generally, the upstream line (ahead of the restriction orifice) has a minimum diameter of 2 in. and is sized for momentum (density multiplied by the square of velocity) less than 30,000 to 50,000 kg/m/s^2 based on the pressure of the system.

The line downstream of the restriction orifice should have a minimum diameter of 2 in. and be sized for momentum (density multiplied by square of velocity) less than 150,000 to 200,000 kg/m/s^2 and Mach number less than 0.7.

Other approaches

Apart from the general arrangement discussed here, other arrangements to reduce pressure or inventory to a more acceptable level can also be used. For instance, in a high-pressure system, there might be two types of depressurization: High-rate depressurization and low-rate depressurization. High-rate depressurizing of plant facilities is typically used to immediately and quickly evacuate equipment inventory in an emergency situation. Low-rate depressurizing of plant facilities is typically used for process control or other operational reasons.

Another option is controlled depressurization. This can be used if the vapor flowrate from calculation is very high. In this arrangement, more than one set of blowdown valves and restriction orifices is used. Initially, only one set is opened and once the pressure has been reduced (after 5–10 minutes), other valves are opened. This way, the vapor flowrate is reduced initially by opening only one valve when the differential pressure is high and it is increased by opening all other valves.

Where the local laws permit it, it can be appropriate to utilize depressurization as an alternative to relief devices sized for the fire case. This scenario typically works best under the following circumstances:

a) The vessel contains only vapor, or has a high-boiling-point liquid;

b) An engineering analysis indicates that the additional protection provided by the relief device would serve little value in reducing the likelihood of a vessel rupture. ■

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From Concept to Commercial Production

These four steps of process development are typically necessary to effectively scale a concept into full production

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Rivertop Renewables

FIGURE 1. Utilizing a scaled-up reactor during laboratory testing enables further in-depth evaluation of process economics, cost-benefit analysis and costs of known dependencies

Chemical technology is in a state of constant innovation and evolution that is being spearheaded by laboratory researchers across the world. Within the past decade, research specific to "green" or bio-based chemicals has gathered funding and momentum as broad-based opinion has shifted toward themes such as sustainability, renewables and conservation. This momentum has impelled advances in green chemistry that are resulting in new products and applications in bioplastics, resins, cleaning supplies, corrosion inhibition and much more as industries look for more economically and environmentally sustainable solutions for the future.

This green boom has led the way for thousands of new patents as innovations are explored and tested across many sectors. Unfortunately, the road from concept to commercial-scale production is often long and arduous, which prevents many from seeing their product ever reach consumers. One of the greatest production challenges to overcome is budgeting the necessary time and resources to develop and scale a product properly. Early stage concepts are constantly under pressure to get up and running as quickly as possible, but a few weeks of commercial scale challenges can cost tens of millions of dollars more than it would have taken to develop a concept systematically.

Assuming market demand is developed and validated, this article discusses the four steps that are generally necessary to effectively scale a concept into full production: 1) proof of concept; 2) laboratory testing; 3) pilot-scale or semi-works development; and 4) commercial production.

Proof of concept

Once a concept for a new technology has been conceived, testing is conducted to demonstrate that the concept works. This process generally involves documenting the invention for patents or publishing by conducting small batch testing to prove a reaction, conversion, or separation actually creates a product that meets performance criteria, such as yield, concentration and reaction rate — or creates a new chemical altogether. Critical issues are identified at this stage, but often this work is limited to proof of performance. It is very important to list these critical issues that need to be solved either before proceeding or during the next stages of development. At this stage, a high-level cost analysis is conducted to identify critical issues concerning the product and its economic viability along with business value hypotheses.

While this early phase of analysis, discovery and proof of performance can be exciting, it is very important for researchers to be as objective as possible when evaluating the pathway forward. During this period, a hypothesis of real commercial value must be developed. Do not let a seemingly good idea blind commercial value analysis.

Best practices. Include stakeholders from across your company including research, engineering, business and finance departments throughout this process. There have been too many instances of companies in the green chemistry space at this stage who neglected to field views from all aspects of the business and the "new technology looking for a problem" won out, when further development of the business case was required.

Laboratory testing

The laboratory testing stage involves early process development, which is aimed at preparing the data necessary to scale to a fully integrated pilot or semi-works facility. During this stage, which is completed in a laboratory, the critical issues identified in the proof-of-concept stage are resolved or abated enough to continue to the next stage. Many times unit operations are identified as conjecture or "anyone skilled in the art…" but never tested at the proof-of-concept stage. Every step in the process is tested and data are developed on the laboratory bench to prove performance and economics of the overall process, generally using standard in-house laboratory equipment (Figure 1) or via vendors. This step is oftentimes skipped completely or not executed fully due to time constraints or impatience. A general estimate of when the laboratory stage is complete is when all necessary information concerning kinetics, vapor–liquid equilibrium, solubility, physical properties, solids separation, and all other relevant properties is known with enough detail to develop a process model using modeling programs. Any gaps in the model are basically gaps in the process knowledge.

The model can then be used to create a mass and energy balance (M&EB), which is used to design and build a fully integrated pilot facility. Once a material balance can be developed, a relatively accurate cost model can be created, which will be the economic basis for the decision to continue development or to cancel the project. The length of laboratory testing varies greatly due to different process complexity and resourcing levels, but it generally takes a minimum of six months to multiple years of experimentation. This step should always include a combination of chemists, chemical engineers, and process and economic modelers and should involve coordination with development partners to ensure product specifications can be met.

Best practices. In the laboratory testing stage, best practices include the following:

- Documentation is key. Ensure that critical issues and solutions identified during this stage are documented along the way. This includes discoveries on the economics of the process, cost-benefit analysis, and costs of known dependencies for the process.
- All these processes usually require multiple steps, often referred to as unit operations. Do not skip or shorten these development steps and be sure to complete each unit operation testing in series, locking in parameters prior to going to the next unit operation. Each successful unit operation is linked to the previous one and many modifications can impact how the next unit operation performs, many times even completely changing the next unit operation.
- In today's technology-driven world, process modeling can help dramatically, both in process speed and the identification of step completion. It is recommended to use first-principle-type data in the model, which are typically available for existing materials and offer significant time efficiencies.
- To help decide if the bio-based chemical or product should be developed, you must further define its commercial value and cost models, while evaluating if the technology has a commercial value that supports moving forward. Again, there is a strong need to involve team members from research, engineering, finance and business departments in this step to make the decision to move forward. However, just as important as internal scrutiny, it is vital to involve an outside project-analysis company to conduct an assessment of your project and provide feedback on the process' readiness to move toward commercialization.

Pilot/semi-works development

Once the laboratory development phase is complete, it is time to move to a fully integrated pilot or semi-works facility, which includes recycle streams and continuous and batch operations capable of uninterrupted running for a minimum of six months. This step is often shortened and not fully integrated with all the recycles, or worse yet, even skipped. Recycle streams, impurity buildups and contamination can have devastating results on a commercial facility. It is critical to know the lifecycle of bio-catalysts or other catalysts, and to learn what contaminants to expect, what fouls them under perfect conditions, or with varying raw materials. Not having detailed data on impurity buildups can eventually cost a project millions of dollars in productivity from contamination, fouling of catalysts, contaminated solvents and lowered capacities (Figure 2).

The capacity of the pilot facility is specifically tailored to minimize the steps necessary to scale from laboratory operations to a commercial facility. Many types of operations, if the correct size is chosen, can be scaled in a single step from a pilot to a commercial facility. A simple example is distillation.

If you build a distillation column in this step that is large enough to minimize wall effects (8-in. dia.), then it could be possible to scale hundreds of times bigger and essentially transition from semi-works to commercial in one step. If your process includes difficult-to-scale unit operations, such as solids separations, then scaling at greater than ten to twenty times is very risky and these types of processes will usually require at least two steps from a pilot and semi-works facility to get to a commercial-scale process. In selecting the number of steps required to scale from pilot- to a commercial-scale facility, it is best to begin by identifying the most challenging unit operation of the process to scale up and then establish the steps necessary to scale up that part of the process.

Upon successfully completing the pilot/semi-works step, a fully developed and integrated process model should be in place, as well as M&EBs and project equipment specifications that can be scaled to commercial levels and be ready to start the front-end-loading of the commercial plant. During this process, partners and customers should be provided or sold samples as further proof that there is a market for the new product. This will provide the process and engineering development team the information necessary to understand the quality requirements for the product. Due to vast differences in emerging technologies and their complexities, the pilot process can take anywhere from one to multiple years. But, by the end of pilot/semi-works development, the capital and operating costs will be fully understood in order to make the decision to go forward with a commercial facility.

Best practices. For pilot-scale or semi-works development, the following are best practices:

- Build a fully integrated facility that includes all recycle streams. In any process, impurities will build up over time as recycle streams are utilized, so understanding what the impurities are and how they affect the process is important. In this step, technologies needed to mitigate any recycle issues should be developed. Waiting until commercial production to learn and address impurity issues can pay for many pilot plant operations in only a few months of failed commercial operations.
- Complete the process model and close all mass and energy loops in the process. By this point in green chemical development, the mass and energy balances should be complete and can be used to develop precise and well-defined operating costs. Also, an early-phase factored capital estimate should be developed at the pilot/semi-works stage in order to have a ±35% capital cost estimate for your final project.
- Given that this is the final step before commercial production, there are several final cross-checks that must be met. These include understanding — and solving — all critical issues, as well as testing and confirming that products manufactured in this stage meet customer requirements.
- While it can be inviting to try to use this phase to make dramatic jumps in production quantities to prove technology readiness, remember to use appropriate scaleup steps and avoid scaling too large. Some processes, such as distillation, scale up very well. However, many others, such as solids separations, do not. Processes involving solids, separations and handling should only be scaled 10 to 20 times, so it may be necessary to do two pilot/semi-works steps prior to being ready for commercial production.
- Again, remember the recurring theme of ensuring involvement from all sides of business (engineering, research and finance), and potentially outside consultants, to review and evaluate the project before moving to the final stage.

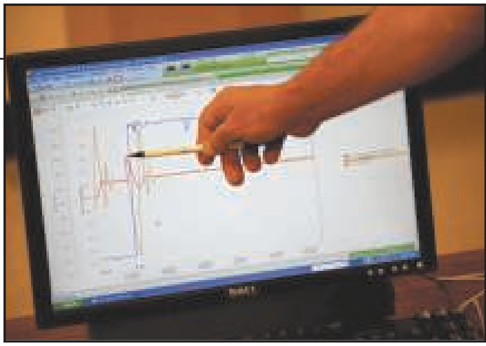

FIGURE 2. **Data collection from a continuous-operating pilot facility is critical to understanding and solving all critical issues with a process before making the jump to the final commercialization stage**

Commercial production

This final step is by far the most costly, but if the preceding steps are completed, the cost can be minimized and quickly recouped with product sales. The high cost is based on the enormous amount of capital and resources required to build, stock, operate and locate the new facility. Many key components go into site selection, including: partners, supply chain, logistics, regulatory permitting, capital funding and taxes. A well-developed project can take only months to start up whereas a poorly developed project can require years and millions of dollars in additional capital and operating costs.

Best practices. For commercial-scale production, the following are best practices:

- As you enter final commercial-scale production, the use of complete process models remains critical, particularly to develop accurate mass and energy balances.
- Conduct thorough front-end loading (FEL) for engineering, including the hiring of an outside project firm to complete an analysis of the FEL results to ensure the process is ready for construction.
- Putting "steel in the ground" can be an exciting and culminating time for a company, but despite any outside pressures from investors or other stakeholders, do not rush into construction. Ultimately construction is the most time- and cost-efficient when it starts at the appropriate time (starting with completely developed FEL) and then increases in speed as the project moves along, as opposed to starting too fast and being sidetracked, leading to a slow, drawn-out project.
- By this point in the project, there will be many stakeholders across all sectors of the business. Ensure that all of these stakeholders agree with the final project objectives and goals, and that the full business proposal is understood and agreed upon.
- In this final stage, dependencies increase and timelines can cross or overlap. To ensure all members of your team understand their responsibilities, it is recommended to establish lines of communication and have the time and resources needed for success. Create a team that spans all parts of business including; quality-control, laboratory, research, engineering, construction, business, financial, supply chain, maintenance, safety, industrial hygiene, operations leadership and plant operators.
- When moving to this scale of operations, and hence product production, government regulations and permitting play an important and unavoidable role in the ability to keep the project on schedule. Do not underestimate permitting issues and dedicate needed personnel resources in advance in order to meet all regulatory requirements and keep the project on schedule.
- Prior to commencing construction, ensure all impacts of site selection have been considered and researched appropriately. Site selection is critical for not only internal plant issues, but also for supply chain costs and logistics for raw materials and products. Often, supply chain costs can be more than conversion costs (manufactur-

ing costs without raw materials).

- Remember it is more important to have a project that makes quality products as quickly as possible than it is to start production on a certain, often arbitrary date. A poorly developed project (incomplete or even skipped development steps) can take months or even years to start up. A well-defined, thought-out project can be up and running quickly.
- After the long road from laboratory to commercial-scale production, a ribbon cutting can feel like the finish line. However, once a plant is up and running, it is crucial to conduct a project debriefing with all stakeholders to evaluate and learn for the next project. Process development is just that, a process that must always continue and improve.

Final thoughts

From an outside perspective, these four steps of process development may appear cumbersome and a burden to innovation. However, they ultimately minimize the costs of investment, thus protecting investors as much as possible and leading to overall success and longterm production. These steps are designed to work as a stage-gate process, proving the processes and products at each step. By the time a concept reaches commercial-scale production, there should be little doubt concerning the innovation's success. This system is successful in minimizing the costs at various stages by preventing millions of dollars in additional costs from correcting scaleup errors or not meeting investor and company expectations. As sustainable innovation and invention continue, we as process developers and engineers will continue to learn and apply improvements to this system. For today, these four steps contain simple and cautious lessons learned that can help any process development reach the commercial scale as efficiently as possible in both costs and timing. ■

Edited by Dorothy Lozowski

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Compressors: N_2 Expands the Applicability of Dry Gas Seals

When the process gas is dirty or corrosive, nitrogen can be used to ensure trouble-free operation of the seal, but it requires special steps

Samir K. Nayek and Leena Chaudhari
Reliance Industries Ltd. India

Ongoing advances in the design and use of dry gas seals (DGSs; [*1*]) — as an alternative to traditional oil-lubricated wet seals [*2*] — have helped to improve the reliability and efficiency of compressors throughout the chemical process industries (CPI). One of the major design considerations in mechanical seals is how to protect seal faces from wear, as one face rotates close to a static face. In traditional oil seals, the use of oil lubrication prevents such wear.

As their name suggests, DGSs are free from wet oil lubrication. Instead, DGSs typically use the process gas to prevent seal wear. When the process gas is dirty or corrosive, nitrogen may be used as an external gas source for seal face lubrication.

DGSs operate on the principle of maintaining micro-level separation (due to fluid-dynamic lift) between the two seal faces. Grooves in the rotating ring generate the necessary seal-gas pressure to maintain a gap of the order of 3 to 10 microns between the seal faces. During operation, this seal gas becomes compressed and the pressurized gas keeps the two seal faces apart. However, a small amount of this gas will get into system.

In DGSs, the seal faces are not in contact with each other so there is no possibility for wear; thus, there is no need for lubrication.

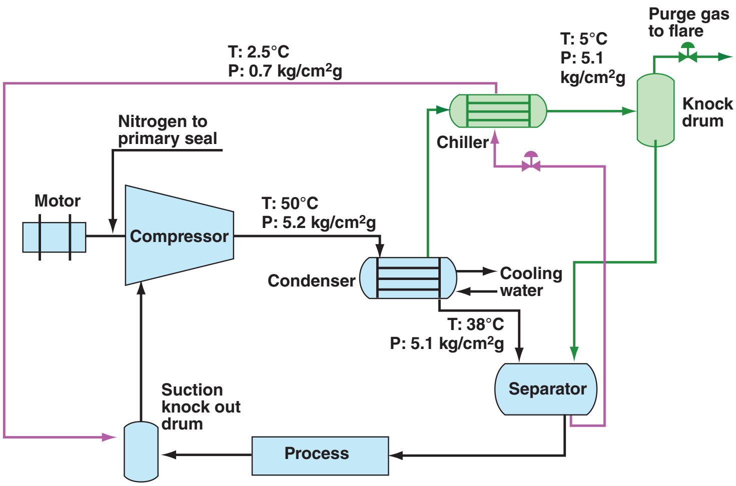

FIGURE 1. This figure shows a compressor system that uses dry gas seals (DGSs). DGSs use nitrogen rather than process gas, for a variety of reasons discussed here

Apart from this inherent reliability, this approach eliminates the cost and hassles of processing the circulating lubrication oil. In general, the replacement of wet seals by DGSs is quite common, and the opportunity for enhanced reliability often justifies such an investment. However, in some isolated applications, compatibility issues between the seal material and the process fluid can be a limiting factor, and will require additional, process-specific steps. One such case is discussed below.

Options and constraints

As noted, the seal gas or gases used in DGSs is compressed by the rotating seal faces. The reliability of the DGSs is absolutely dependent on a reliable supply of a high-quality seal gas. The presence of particulate matter, liquid droplets or other incompatible chemicals may interfere with and damage seal faces and cause seal failure, leading to machine stoppages. Ideally, the seal gas must be clean, non-condensing, and compatible with the seal faces.

The lowest-cost and most-convenient option is to use a slipstream of process gas from the compressor discharge. In many applications, the use of the process gas or some non-condensable components of the process fluid — supported by the use of an application-specific, gas-conditioning system with a sophisticated control system — is quite common.

Auxiliary systems that include high-efficiency filtration and the provision of superheating capabilities are often adequate for treating the process gas to meet the seal-gas specifications. The costs associated with such a secondary treatment system must be factored into the decisionmaking when it comes to selecting the most appropriate seal gas. In some cases, such an analysis will reveal that the economics of adding a process-gas-conditioning system (to meet the stringent seal-gas specifications) is unfavorable.

In some applications, the presence of highly corrosive chemicals in the process gas may rule out its use as the seal gas in DGSs. However, in these cases, the use of a clean, external gas, such as nitrogen, may be considered as an alternative. This is especially useful at integrated sites where nitrogen is available onsite as a utility. The use of an external source of seal gas is a feasible and practical option for eliminating risk of seal damage that could occur due to the failure of treatment systems, or because of a drop in process gas pressure [*1*].

Impact of an external seal gas

The principle of functioning of DGSs requires a very small ingress of seal gas to the process side of the compressor. In some applications, this could lead to process-fluid contamination. Although good design can restrict this small source of "leaked" gas to a minimum, its impact — unless evaluated and addressed — may lead to operational problems.

In some cases, the process is able to integrate this minor ingress of clean, inert nitrogen without any further concern. But in other cases, an exit strategy — such as the use of chemical or physical means, such as reaction, solution or purging — must be used to remove this leaked gas from the system downstream of the compressor. Again, the system complexity and costs associated with these options will vary from system to system and will influence whether or not the use of a dry gas seal is appropriate for a given application.

Refrigeration compressor loop

The refrigeration compressor discussed in this case history is used to compress isobutane (iC_4) vapor that is generated in the process plant. Compressed vapor gets condensed in a water-cooled condenser and the liquid refrigerant is supplied back to process.

It is considered that the process gas from the compressor discharge will not meet the required seal-gas specification due to the presence of contaminants. Since the treatment of the process gas to remove the contaminants is not economical in this case, the use of nitrogen is the preferred alternative seal gas for this application.

As mentioned above, a small amount of nitrogen will get into the process system through the seal faces and thus flow with the iC4 vapor to the condenser (Figure 1). Since nitrogen is non-condensable, it will accumulate in the condenser and thus affect the condensation of the iC_4 vapor, thereby increasing the compressor discharge pressure.

The use of non-condensable venting from the far end (that is, from the vapor-entry point) of the condenser is a standard remedy to the occasional non-condensable blanketing problem. Continuous purging to get rid of the continuous ingress of nitrogen is not likely to be economical. Although the amount of nitrogen that gets into the process is small, the use of a continuous purge will lead to a significant loss of associated iC_4.

Being saturated with iC_4 vapor, the composition of the purge gas will vary as a function of the operating pressure and cooling-water temperature. At the condensation temperature for iC_4, with cooling water (supply temperature at 32°C), this purge stream will have about 82 vol.% iC_4 at the pressure (at 5 kg/cm^2) used for this calculation. A continuous purge mode will lead to substantial loss of the associated iC_4 with the nitrogen, making this scheme uneconomical.

Ingress of, say, 100 kg/h of nitrogen will lead to about 1 m.t./h iC_4 loss to the flare. To reduce this loss, the temperature of the purge stream can be reduced through a chiller, as shown in the figure. With respect to loss reduction, the lower the temperature, the better. In the application shown in the figure, we use 5°C.

Refrigerant vapor from this chiller is led to the compressor suction. The chiller pressure is, by design, kept to a minimum (the lowest possible value, as limited by the compressor suction pressure). At low temperatures, the iC_4 from the purge stream will condense and will be routed to the separator by gravity. The extent of the recovery of iC_4 depends on the chiller temperature, and, in turn, by the suction pressure of the compressor. At conditions shown in the figure, this loss can be reduced to the order of 100 kg/h.

Closing thoughts

While in principle the scheme described here is too simple to be debated, its application must still be determined by a cost-benefit analysis. The total cost of nitrogen, the costs of the loss of associated iC_4, and the cost of refrigeration (to operate the chiller) must be weighed against the operating cost of the wet seal and the anticipated increase in reliability of the DGSs.

In the replacement case discussed here, the refrigerant compressor may become overloaded with this additional chiller load. Since the actual operating cost and considerations will vary from place to place, no attempt is made here to present a fit-for-all conclusion. Further, the cost of potential seal failure (associated with the use of oil-lubricated seals) and the consequent downtime for the process is a factor of process and its profitability.

For safety reasons, nitrogen systems are normally robust and highly reliable in refineries and petrochemical complexes. This often helps to justify the use of nitrogen as an alternative to process gas with a gas-treatment system to support the use of DGS in compressor applications. ■

Edited by Suzanne Shelley

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Fractionation Column

Team building

Have you ever participated in a team-building exercise, the type where Human Resources personnel teach a group of individuals how to work better together? I'll bet that during my career I participated in about ten such exercises, but right now I only remember two.

The Men-on-the-Moon exercise was a great one. You were asked to imagine that you had crash-landed on the Moon and you were allowed to take only 10 of 20 items outside of the space capsule with you. Would you take a gun, a tent, matches or cell phone? You submitted your answers as individuals. Then, all participants sat together, talked it over and submitted a group answer. Real astronauts composed the answer sheet. In our case, the group out-performed all of the individuals. Working together, the team had most of the answers.

In another team-building exercise, 30 people were divided into three groups. Each group stood on a hot asphalt parking lot and formed a circle and held a rope at waist level. I did not know what that exercise was all about then, and I sure don't know now.

I have entered many industrial columns during my career. All of those entries have been through manholes on the sides of the columns. The FRI test columns are different. The heads come off. The columns are entered via a chair, and ropes and an overhead winch. Three years ago, we authored a new safety policy named "First Time Column Entry." It was intended to provide training and practice to rookie entrants, before their first entrance.

We try to review each FRI safety policy every three years. A month ago, it was time to review "First Time Column Entry." I asked FRI's ultra-capable administrative assistant, Joella Redden, if she would be willing to review the policy by being the first member of the administration staff and the first woman to be lowered into a column. Her answer was ultra-affirmative.

When the big day came, Terry Thurber gave Joella the requisite training. I expected Terry and one other technician to assist her with the actual column entry. I did not expect the entire technician staff to participate — but they did. They were all fully committed and fully focused on just one goal — protecting Joella. The somewhat-unusual event turned into the best team-building exercise in the history of FRI.

The column entry and the column exit went totally smoothly. Terry reported that, "The last three men that entered the column for the first time squealed like little girls when we suspended them in the swing high above the empty column; Joella just smiled." Most importantly, Joella and Terry made assorted significant changes in the procedure. Column entries will be even safer in the future.

Teamwork happens every day. Teamwork is all around us. Unfortunately, certain team members perform the same roles, again and again. They find their comfort zones or their managers assign them to those zones. To build a team or to improve a team, the team needs to be shaken up. They need to crash land on the Moon, or hold a rope in a parking lot, or protect Joella as she enters a distillation column for the first time. ■

Mike Resetarits

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

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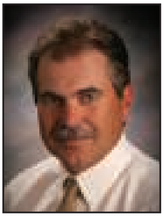
JUNE WHO'S WHO


Kraemer


Garber


Prejean


Schaub


Watson

Kenneth Lane becomes president of **BASF**'s Catalysts Div. (Iselin, N.J.), succeeding *Frank Bozich*, who has decided to leave the company.

Klüber Lubrication North America LP (Londonderry, N.H.) names *Ralf Kraemer* CEO. He succeeds *Dieter Becker*, who returns to Klüber's global headquarters in Munich, Germany.

Heather Rayle becomes senior business director at specialty chemicals maker **Sartomer USA LLC** (Exton, Pa.).

Mark Yingling joins **The Doe Run Co.** (St. Louis, Mo.), a natural resources company and producer of lead, as vice-president of environmental health and safety.

Technology provider **GEA Process Engineering Ltd.** (Düsseldorf, Germany), names *David Wilkinson* automation service manager to support automation control systems throughout the U.K.

Greene's Energy Group (GEG; Houston), a provider of testing services and rentals for drilling, pipeline and process operations, makes the following announcements: *Gene Garber* becomes chief integration officer; *Blayne Prejean* becomes operations manager of GEG's Cherokee Services division; and *Elroy Schaub* becomes technical sales representative.

Moore Industries International (North Hills, Calif.), a maker of electronic measurement and interface instruments, hires *Tom Watson* as its new corporate marketing manager. ■

Suzanne Shelley

BUSINESS NEWS

PLANT WATCH

Evonik plans new precipitated-silica plant in Brazil

May 10, 2013 — Evonik Industries AG (Essen, Germany; www.evonik.com) has started basic engineering for a precipitated-silica plant in Brazil. Subject to the approval of the responsible bodies, Evonik aims to complete the plant in 2015. The planned facility in Americana, with an investment level in the middle double-digit million-euro range, would be Evonik's first silica production facility in South America. The company has also announced plans to expand its annual capacity for precipitated silica at the U.S. American Chester site by around 20,000 metric tons (m.t.). The U.S. plant, with an investment in the lower double-digit million-euro range, is planned to come onstream in 2014.

NPN to build $1.5-billion nitrogen-fertilizer plant in North Dakota

May 9, 2013 — Northern Plains Nitrogen (NPN; Grand Forks, N.D.; www.northernplainsnitrogen.com) has announced plans to build and operate a $1.5-billion nitrogen-fertilizer production facility near Grand Forks, N.D. The facility will include a 2,200-ton/d ammonia plant, plus urea and urea-ammonium-nitrate (UAN) production facilities. The facility will be located on land adjacent to the Grand Forks Wastewater Treatment Plant. It is expected that the plant will be completed in time for the 2017 growing season.

Commercial debut of the AlkyClean solid-acid alkylation process

April 30, 2013 — CB&I (The Woodlands, Tex.; www.cbi.com) has been awarded a contract by Shandong Wonfull Petrochemical Group Co. to provide the license and process engineering design for a first-of-a-kind solid-acid alkylation unit to be located in China. The unit will be capable of producing 100,000 ton/yr of alkylate and is scheduled for startup in early 2014. The unit will use the AlkyClean process technology (for more information, see p. 11), developed by CB&I's Technology operating group, Albemarle Corp. (Orangeburg, S.C.) and Neste Oil (Espoo, Finland).

Sulzer awarded contract for biopolymer production plant in Asia

April 25, 2013 — Sulzer Ltd. (Winterthur, Switzerland; www.sulzer.com) has been awarded a contract for the delivery of a production plant based on Sulzer's proprietary polylactic acid (PLA) technology (for more process details, see *Chem. Eng.*, March 2012; www.che.com/chementator/9161.html). The facility, with a capacity of more than 10,000 ton/yr, will produce high-performance PLA for a broad range of applications. Commercial production is planned to start in the 2nd half of 2014.

BASF and Petronas to build an integrated aroma-ingredients complex in Malaysia

April 25, 2013 — BASF SE (Ludwigshafen, Germany; www.basf.com) and Petronas Chemicals Group Berhad (PCG; Kuala Lumpur, Malaysia; www.petronaschemicals.com) intend to invest $500 million (MYR 1.5 billion) in an integrated aroma-ingredients project at their existing joint-venture site BASF Petronas Chemicals in Gebeng, Kuantan. At the heart of the complex will be a plant for citral, and precursor plants. The partners will also invest in downstream production for aroma ingredients including a new plant for L-menthol and a plant for citronellol. Production will be developed in phases, with the first plants of the project operational in 2016.

KBR to provide technology and services for grassroots ammonia plant

April 17, 2013 — KBR (Houston; www.kbr.com) has been awarded a contract by Incitec Pivot Ltd.'s U.S. business, Dyno Nobel, to provide engineering, procurement and construction (EPC) services, as well as technology licensing and equipment, for an ammonia plant to be built in Waggaman, La. The contract award is valued at approximately $600 million. The 800,000-m.t./yr ammonia facility will be designed using KBR's Purifier technology.

Solvay plans to build large-scale alkoxylation facility in Singapore ...

April 16, 2013 — Solvay S.A. (Brussels, Belgium; www.solvay) says that it will build a large-scale alkoxylation facility in Singapore, which is expected to start operations by 2015. The facility will be connected to Shell's new high-purity ethylene oxide (HPEO) unit located in the integrated petrochemical hub of Jurong Island. Through the alkoxylation process, key monomers are produced that serve downstream surfactant development and manufacturing.

...and plans to build a specialty surfactant plant in Germany

April 12, 2013 — Solvay S.A. has announced that it will build a specialty surfactant plant at an industrial park in Genthin, Germany, close to Berlin. The unit will develop and produce surfactant solutions for Solvay's home and personal care products, and for industrial customers serving Central and Eastern Europe. The unit is scheduled to be operational by the 1st Q of 2014.

Sener and Obrascón Huarte Lain to build a cogeneration plant in Mexico

April 10, 2013 — Pemex Refinación (Huasteca, Mexico; www.ref.pemex.com) has awarded to a consortium — formed by Sener (Madrid, Spain; www.sener.es) and the industrial division of the company Obrascón Huarte Lain — a turnkey project for the construction of a 35-MW cogeneration plant in its Francisco I Madero petroleum refinery, located in the state of Tamaulipas, Mexico. The facility will be equipped with a heavy-duty type gas turbine as well as with a heat-recovery steam generator (HRSG). Supplementary combustion associated with the gas turbine will generate 115 ton/h of steam at a pressure of 19 kg/cm² and 275°C. This steam will be used within the refinery in the production process of the new gasoline- and diesel-desulfurization plants. Sener and the industrial division of Obrascón Huarte Lain will manage the project in full coordination in a "Full Joint Venture" structure, in which there is no division of responsibilities for each company.

MERGERS AND ACQUISITIONS

Solvay and Ineos join forces to create a world-class PVC producer

May 7, 2013 — Solvay S.A. and Ineos AG (Rolle, Switzerland; www.ineos.com) have signed a Letter of Intent (LOI) to combine their European chlorvinyls activities in a proposed 50-50 joint venture (JV). The combination would form a polyvinyl chloride (PVC) producer ranking among the top three worldwide, says Solvay. The combined business would pool each company's assets across the entire chlorvinyls chain. This includes PVC, which is the third most-used plastic in the world, caustic soda and chlorine derivatives. RusVinyl, Solvay's Russian joint venture in chlorvinyls with Sibur, is excluded from the transaction. Until completion of the transaction, which is dependent on approval and procedures, Solvay and Ineos will continue to run their PVC businesses separately. ■

Dorothy Lozowski

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

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FOR MORE ECONOMIC INDICATORS, SEE NEXT PAGE

2011 — 2012 — 2013

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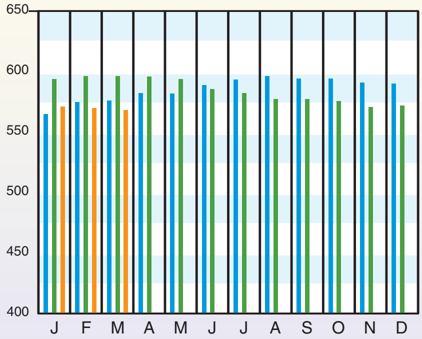
CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957–59 = 100)	Mar.'13 Prelim.	Feb.'13 Final	Mar.'12 Final
***CE* Index**	568.3	569.9	596.1
Equipment	688.3	690.9	729.9
Heat exchangers & tanks	624.2	627.4	686.6
Process machinery	651.1	653.8	680.7
Pipe, valves & fittings	879.8	887.6	934.8
Process instruments	414.5	417.0	433.9
Pumps & compressors	920.4	917.4	922.2
Electrical equipment	514.4	513.5	513.6
Structural supports & misc	741.1	739.3	772.1
Construction labor	319.0	318.9	323.0
Buildings	534.2	530.9	526.2
Engineering & supervision	326.9	326.6	327.8

Annual Index:

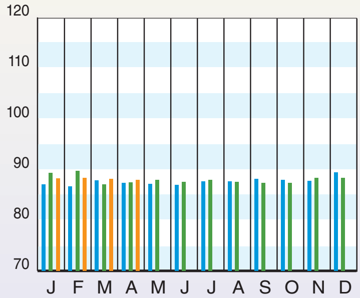
2005 = 468.2
2006 = 499.6
2007 = 525.4
2008 = 575.4
2009 = 521.9
2010 = 550.8
2011 = 585.7
2012 = 584.6



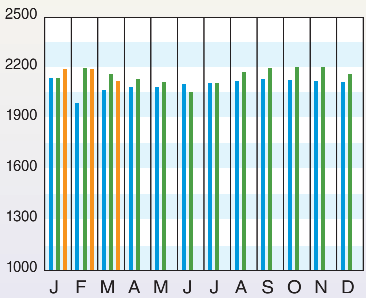
CURRENT BUSINESS INDICATORS

	LATEST			PREVIOUS						YEAR AGO		
CPI output index (2007 = 100)	Apr.'13	=	87.9	Mar.'13	=	88.1	Feb.'13	=	88.3	Apr.'12	=	87.4
CPI value of output, $ billions	Mar.'13	=	2,123.10	Feb.'13	=	2,192.70	Jan.'13	=	2,195.40	Mar.'12	=	2,167.30
CPI operating rate, %	Apr.'13	=	74.3	Mar.'13	=	74.6	Feb.'13	=	74.8	Apr.'12	=	74.9
Producer prices, industrial chemicals (1982 = 100)	Apr.'13	=	308.7	Mar.'13	=	313.5	Feb.'13	=	314.2	Apr.'12	=	328.9
Industrial Production in Manufacturing (2007=100)	Apr.'13	=	95.2	Mar.'13	=	95.6	Feb.'13	=	95.8	Apr.'12	=	93.9
Hourly earnings index, chemical & allied products (1992 = 100)	Apr.'13	=	154.3	Mar.'13	=	154.8	Feb.'13	=	155	Apr.'12	=	159.6
Productivity index, chemicals & allied products (1992 = 100)	Apr.'13	=	104.2	Mar.'13	=	104.7	Feb.'13	=	104	Apr.'12	=	106.8

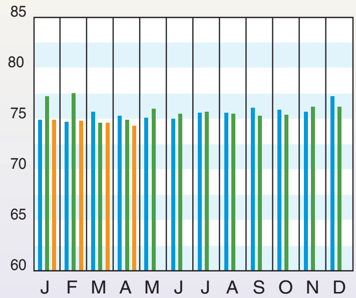
CPI OUTPUT INDEX (2007 = 100)



CPI OUTPUT VALUE ($ BILLIONS)



CPI OPERATING RATE (%)



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

CURRENT TRENDS

Preliminary data for the March 2013 *CE* Plant Cost Index (CEPCI; top; the most recent available) indicate that the composite index declined by 0.3% from the February value. The decrease was driven by a lower overall equipment cost index. The indices for construction labor, buildings and engineering & supervision edged higher. The March decline follows a similar 0.2% dip the previous month. The March 2013 preliminary PCI stands at 4.6% lower than the corresponding final PCI value from March 2012. Meanwhile, the latest Current Business Indicators from IHS Global Insight (middle) all edged lower compared to the previous month. For example, the CPI output index for April dropped to 87.9 from 88.1 in March. ■