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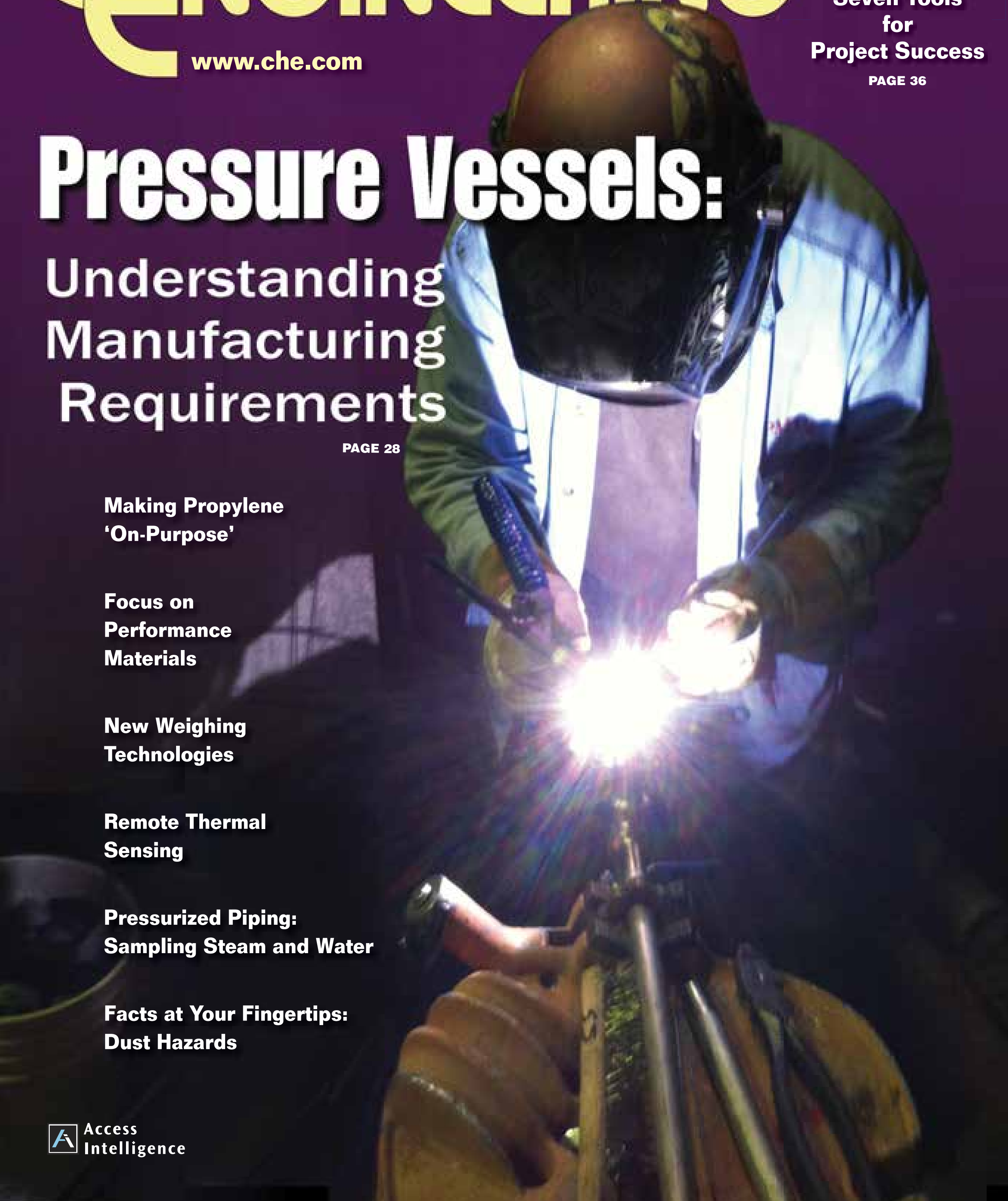

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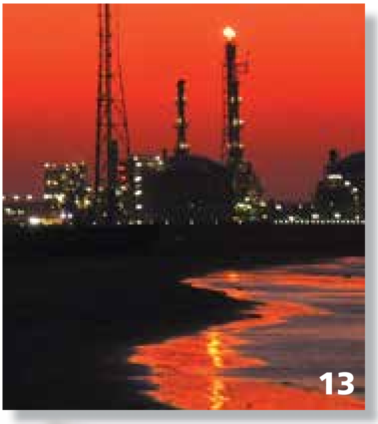

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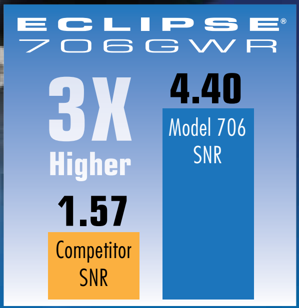

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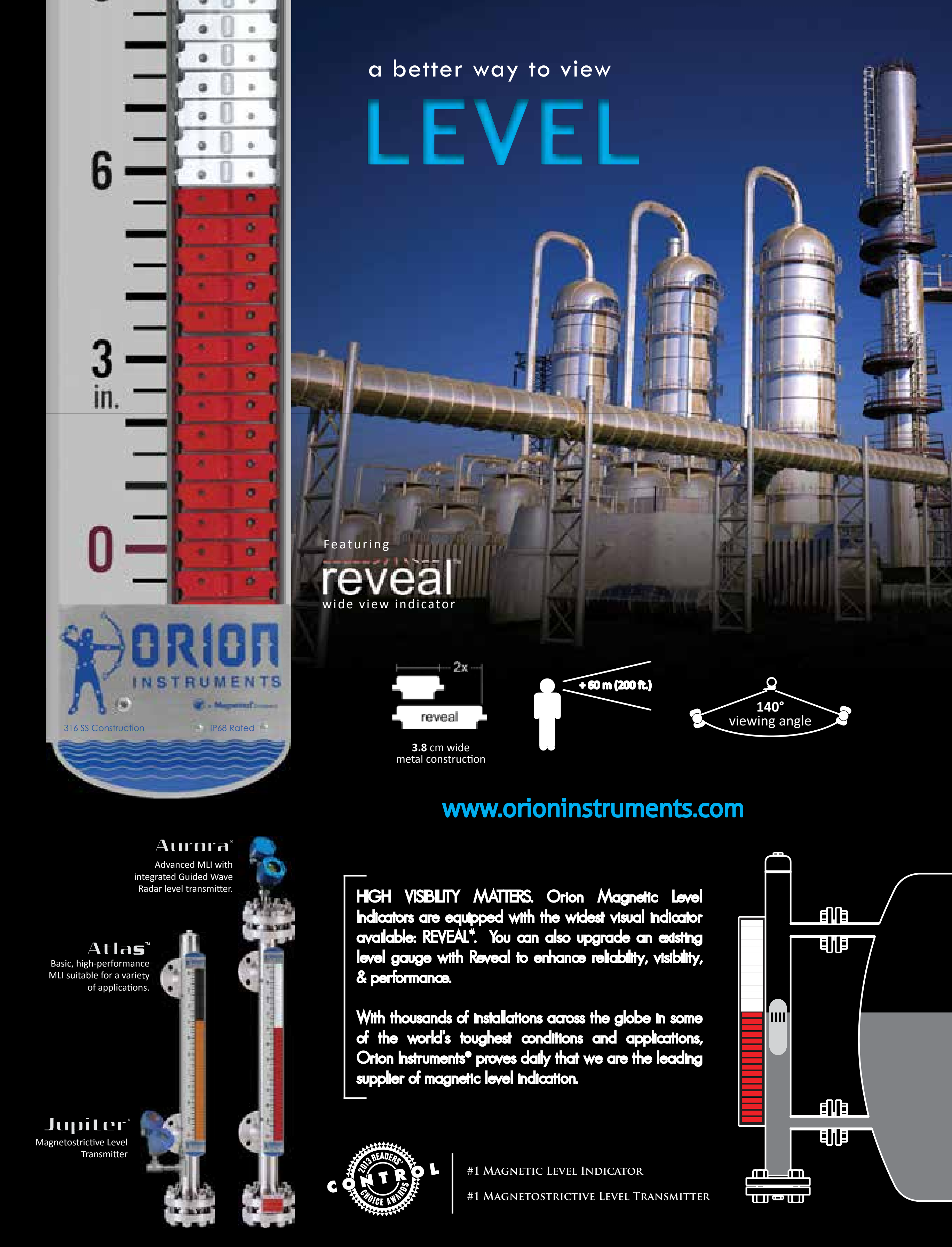

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Editor's Page

Honoring personal achievement

Do you know someone whom you would describe as having a distinguished career in chemical engineering? Perhaps it is someone you have admired, or who has inspired you. If you would like to bring recognition to that person, consider nominating him or her for our 2014 Award for Personal Achievement in Chemical Engineering.

The Personal Achievement award, which *Chemical Engineering* (*CE*) has bestowed every other year since 1968, honors individuals for distinguished careers in which chemical engineering principles have been applied to solve problems in industrial, community or governmental service. The award recognizes achievements in a variety of areas, such as research and development, plant operations, management and more.

The Personal Achievement award focuses on an indivdual's contributions, and thus complements *CE*'s Kirkpatrick Chemical Engineering Achievement Award — presented in the alternate years — that recognizes companies for specific accomplishments in new chemical process technology.

How to nominate. Submitting an award is simple:

1. State the name, job title, employer and address of the candidate.
2. Prepare a summary, in up to about 500 words, that highlights your nominee's career and brings out his or her creativity and general excellence in the practice of chemical engineering technology. At least some of the activity must have taken place during the three-year period ending Dec. 31, 2013. Please be specific about key contributions and achievements, but do not include confidential information.
3. Please be sure to include your own name and address in case we need to contact you.
4. Send your nomination no later than April 15 to:

Cristane Martin
Chemical Engineering
TradeFair Group
11000 Richmond Ave., Suite 690
Houston, TX 77042
Email: awards@che.com

To aid the judging process, we encourage you to ask others to provide information to us in support of the nominee, by April 15.

Next steps. Once we receive a nomination, we will ask the candidate whether he or she is willing to be considered in the competition. You may instead do this yourself, and inform us in your nomination. We may take steps, as deemed appropriate, to verify the accomplishments stated in the brief or supporting letters.

The nominations will then be sent to a panel of senior chemical engineering educators for evaluation and ranking. Based on the voting of these judges, we will designate one or more winners. Then we will inform nominees and nominators of the voting results. Winners will be presented with the award and featured in an article in *CE* in late 2014.

Additional points. Nominees can be from any country. While they do not need to have a degree in chemical engineering, their achievements must involve the use of chemical engineering principles in problem solving, and part of that activity must have been in 2011–2013.

In preparing your nominating brief, it may be helpful to read about past winners of this widely recognized award (*CE*, pp.17–20, December 2012). ■

Dorothy Lozowski, Editor in Chief

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Letters

ISA is accepting applications for 2014 scholarships

The International Society of Automation (ISA) is accepting applications for a wide range of 2014 educational scholarships, which will be awarded to college and university students who demonstrate outstanding potential for long-range contributions in the fields of automation, instrumentation and control.

ISA educational scholarships, which fund tuition, related expenses and research initiatives, are distributed annually to undergraduate students in two-year and four-year colleges and universities, and to graduate students. More than $65,000 in scholarship funds are expected to be distributed in 2014. The two top undergraduate winners will receive $5,000 each. Other award amounts will vary.

Interested students are encouraged to apply as soon as possible by submitting a completed application form, which can be found on the ISA website (www.isa.org), or by calling ISA at 919-549-8411. The application deadline is February 15, 2014.

ISA awards scholarships from the ISA Educational Foundation Scholarship fund; through the ISA Executive Board; through ISA technical divisions, sections and districts; and through endowments of generous gifts from supporters. More details on these various scholarships are included below.

Educational Foundation Scholarship. Recipients of these awards are full-time college or university students in either a graduate, undergraduate, or two-year degree program with an overall grade point average of at least 2.5 on a 4.0 scale. Students should be enrolled in a program in automation and control or a closely related field.

ISA Executive Board Scholarship. These funds are provided by past and present members of ISA's Executive Board. Preference is given to applicants with demonstrated leadership capabilities. The award amount varies.

Named awards. Funds are provided by families or groups in honor of specific people.

ISA technical division scholarships. Funds are provided by specific ISA divisions. Scholarships are given to outstanding students pursuing careers in the area pertinent to the division's activity. All ISA divisions, except the Chemical and Petroleum Industry Div. (ChemPID) and the Food and Pharmaceutical Industries Div., request that completed applications be sent to a specific person (identified on the ISA technical division scholarships page).

ISA section and district scholarships. Funds are provided by specific ISA sections and districts.

For more information, see the ISA website.

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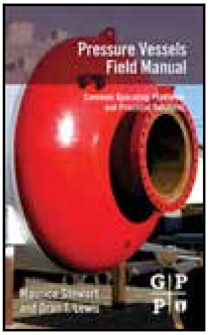

Pressure Vessels Field Manual: Common Operating Problems and Practical Solutions. By Maurice Stewart and Oran T. Lewis. Gulf Professional Publishing, 2 Greenway Plaza, Suite 1020, Houston, TX 77046. Web: gulfpub.com. 2013. 498 pages. $79.95.

Reviewed by Keith Kachelhofer, Hargrave Engineers + Constructors, Savannah, Ga.

In this book, authors Maurice Stewart and Oran Lewis provide concise information from the ASME Boiler & Pressure Vessel Code Section VIII, Divisions I and II (the Code). Unlike most material published on the topic of pressure vessels, this book provides practical information for day-to-day operations for designing, fabricating and repairing pressure vessels.

Information in the book is organized into an outline format that provides key information on each topic. The format makes it easy for the reader to quickly find information.

The book starts with the history and organization of the ASME presssure vessel codes, followed by sections on vessel materials of construction, mechanical design, fabrication, welding and in-shop inspection. The order of chapters, as well as the order of information with each chapter, follows the processes needed to design and fabricate a pressure vessel.

Two chapters are dedicated to materials of construction for pressure vessels, and they cover both ferrous and nonferrous alloys, along with information on heat treatment and hydrogen embrittlement. Additional topics include aluminum alloys, Charpy V-notch testing, fracture-analysis diagrams and brittle fractures.

The authors have done a good job discussing the responsibilities of all stakeholders — the owner, user and manufacturer — for both Division I and Division II of the ASME Boiler and Pressure Vessel Code. Calculation procedures from the Code are provided for internal pressure and external pressure of cylinders and various heads. The example calculations that are included are easy to follow.

The last three chapters separate this book from others on the topic. Full color photographs are presented, showing the various processes that take place in a vessel fabrication shop. The pictures range from shell fit-ups and nozzle installations to hydrostatic testing.

This is a good reference book for engineers in the chemical process industries (CPI), whether they have extensive, or only limited, exposure to pressure vessels.

Recently published books

Wireless Networks for Industrial Automation. 4th ed. By Dick Caro. International Society of Automation, 67 T.W. Alexander Drive, Research Triangle Park, NC 27709. Web: isa.org. 2014, 109 pages. $99.00.

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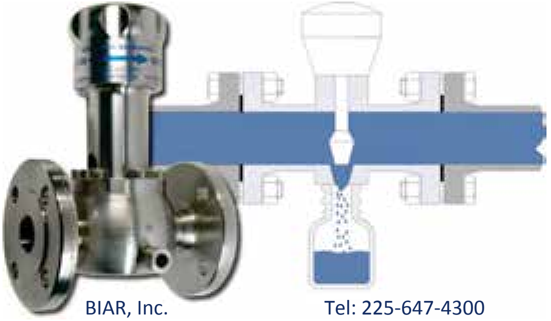

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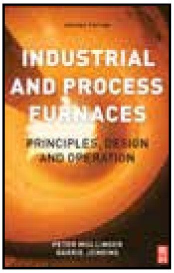
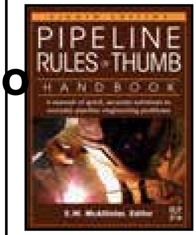
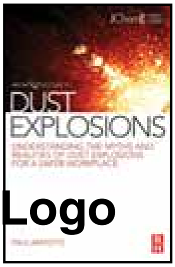


Industrial and Process Furnaces: Principles, Design and Application. 2nd ed. By Peter Mullinger and Barrie Jenkins. Elsevier, Butterworth-Heinemann, 225 Wyman Street, Waltham, MA 02144. Web: elsevier.com. 2013. 680 pages. $149.00.



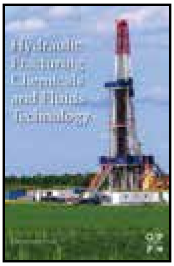
2012 Renewable Energy Data Book. By Rachel Gelman, National Renewable Energy Laboratory. U.S. Dept. of Energy, 1000 Independence Ave. SW, Washington, DC 20585. Web: nrel.gov. 2013. 128 pages (PDF). Free publication.

Pipeline Rules of Thumb Handbook. 8th ed. Edited by E.W. McAllister. Gulf Professional Publishing, 2 Greenway Plaza, Suite 1020, Houston, TX 77046. Web: gulfpub.com. 2013. 806 pages. $101.96.

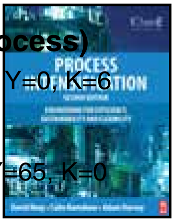


An Introduction to Dust Explosions: Understanding the Myths and Realities of Dust Explosions for a Safer Workplace. By Paul Amyotte. Elsevier, Butterworth-Heinemann, 225 Wyman Street, Waltham, MA 02144. Web: elsevier.com. 2013. 280 pages. $37.46.

Activated Sludge Technologies for Treating Industrial Wastewaters: Design and Troubleshooting. By W. Wesley Eckenfelder and Joseph Cleary. DESTech Publishing Inc. 439 North Duke Street, Lancaster, PA 17602. Web: destechpub.com. 2013. 234 pages. $89.50.



Hydraulic Fracturing Chemicals and Fluids Technology. By Johannes Fink. Gulf Professional Publishing, 2 Greenway Plaza, Suite 1020, Houston, TX 77046. Web: gulfpub.com. 2013. 248 pages. $74.96.



Process Intensification: Engineering for Sustainability, Efficiency and Flexibility. 2nd ed. By David Reay, Colin Ramshaw and Adam Harvey. Elsevier, Butterworth-Heinemann, 225 Wyman Street, Waltham, MA 02144. Web: elsevier.com. 2013. 624 pages. $112.50. ■

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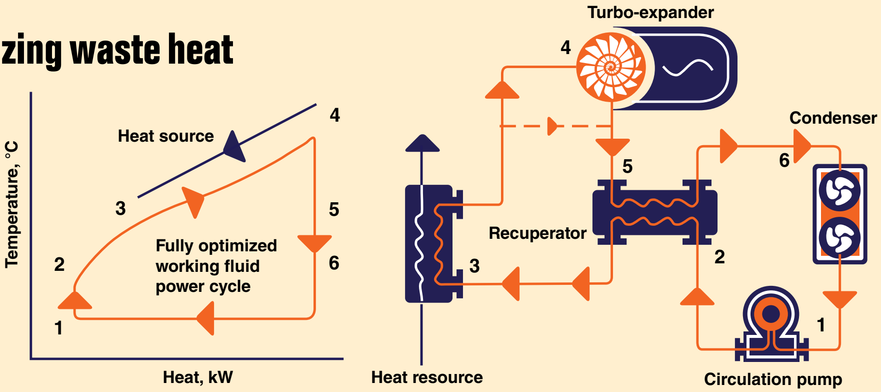
CHEMENTATOR

Edited by Gerald Ondrey

January 2014

An efficient cycle for utilizing waste heat



An Australian team has implemented several changes to the conventional organic rankine cycle, resulting in a highly efficient regenerative thermodynamic cycle for producing electricity from waste heat and other thermal sources. The University of Newcastle's Priority Research Center for Energy (www.newcastle.edu.au), led by professor Behdad Moghtaderi and working with Granite Power Ltd. (Sydney; www.granitepwr.com), discovered that by bringing the working fluid to a supercritical state in the boiler — as is done in modern large thermal power stations — avoids a temperature mismatch between the heat source and the working fluid. Granite Power claims the technology offers up to a 50% improvement in net electricity that can be generated from a given heat source. The technology has been registered under the tradename Granex.

In the closed-loop Granex power cycle (diagram): 1) the cool liquid is pressurized in a pump; 2) the pressurized liquid is preheated in a recuperator; 3) warm pressurized liquid is further heated to a supercritical state by a hot resource; 4) the hot supercritical fluid is expanded in the turbo expander; 5) low pressure, hot vapor is de-superheated in the recuperator; and 6) low pressure warm vapor is condensed and returned to the pump suction.

The team tested several working fluids, and then demonstrated the system in a 100-kW plant. The testing validated the temperature limits these various working fluids could be brought to without degradation, thus enabling this cycle to operate at a higher working temperature than standard organic rankine cycles.

The team is in the final commissioning phase of a demonstration plant at Wallsend, Newcastle, integrating the Granex technology with a concentrated-solar-thermal heat source. The team claims that this is the first system where the supercritical fluid is directly heated in the receivers of the solar field. This eliminates the need for an intermediate fluid, such as thermal oil or molten salt, that is typically used between the solar field and the power cycle.

The plant features an integrated turbine generator developed by Granite Power and the university. The turbine generator has a permanent-magnet rotor designed to deliver 30 kW at 70,000 rpm. This high speed matches the turbine tip speed to achieve the best efficiency and eliminate the need for a reduction gearbox.

Bacteria make lactic acid from palm waste

Extraction of palm oil generates large amounts of lignocellulose-rich byproduct known as empty fruit bunch (EFB), which is usually wasted. A new process for utilizing this waste to make lactic acid has been developed by a team of researchers in Singapore.

Up to now, it has been difficult to find cost-effective processes for the production of L-lactic acid, which has inhibited the commercial production of lactic acid from agricultural waste. Optically pure L-lactic acid is currently produced at a high cost from starchy materials, such as cornstarch. Most micro-organisms cannot easily digest all of the sugars in EFB, which must be used for the process to be cost-effective. Now, scientists from the Institute of Chemical and Engineering Sciences, Agency for Sciences, Technology and Research (A*STAR; www.a-star.edu.sg), and the Dept. of Chemical and Biomolecular Engineering, Faculty of Engineering, National University of Singapore (www.nus.edu.sg) have identified bacteria that convert waste from palm oil into lactic acid.

(Continues on p. 11)

Sludge dewatering

Last month, Metso Corp. (Helsinki, Finland; www.metso.com) introduced what it claims to be the world's first advanced solution — both measurements and control system — to optimize sludge dewatering at wastewater treatment plants. The Metso SDO (sludge dewatering optimizer) uses Metso measurements and an advanced control application, which is said to be essential for optimization since the dewatering unit control is a nonlinear process. "Through optimization, wastewater treatment plants are able to improve sludge-dewatering-unit performance by up to 50% and reduce consumption of chemicals used in dewatering by 50%," says Heli Karaila, product manager, Measurement, Automation at Metso.

Isobutene pilot plant

Global Bioenergies (Evry, France: www.bioenergies.com) plans to construct its second industrial pilot plant on the site of the Leuna Refinery near Leipzig, Germany. Supported by the German Federal Ministry of Education and Research (BMBF; Bonn) through a €5.7-million grant, the new pilot plant is part of a three-year research study at the Fraunhofer Center for Chemical-Biotechnological Processes (CBP; Leuna, Germany; www.cbp.fraunhofer.de). The pilot will combine two 5,000-L fermenters and a complete purification system, and

(Continues on p. 11)

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

Novel co-catalyst system could enable CO_2-to-syngas processes

A metal-free catalyst system involving ionic liquids and doped carbon nanofibers can efficiently reduce carbon dioxide to carbon monoxide, offering a cost-effective electrochemical route from CO_2 to synthesis gas (syngas), and further, to liquid transportation fuels.

A research group at the University of Illinois at Chicago (UIC; www.uic.edu), led by Amin Salehi-Khojin, demonstrated that graphite-like nanofibers doped with nitrogen heteroatoms within the carbon lattice selectively convert CO_2 to CO in an electrochemical reaction that has a current density 13 times that of bulk silver. This noble metal catalyst was studied previously in the group's laboratory.

Previous research in the area of CO_2 reduction has generally employed a single catalyst to effect what is really a two-step electrochemical reaction, Salehi-Khojin explains. In the group's co-catalyst system, an ionic liquid (1-ethyl-3-methylimidazolium tetrafluoroborate; EMIM-BF_4) forms a complex with CO_2 molecules, then the CO_2 is reduced to CO by the doped carbon nanofiber structure, he says. "The co-catalyst system shows significant synergistic effects compared to silver, in this reaction," Salehi-Khojin remarks.

Careful experimentation by graduate student Mohammad Asadi and post-doctoral fellow Bijandra Kumar, among others, found that the dopant atoms participate only indirectly in the electrochemical reduction of the CO_2-EMIM complex. Rather than serving as the catalytic site itself, nitrogen atoms doped into the carbon lattice (via a standard pyrolysis process) activate the adjacent carbon atoms, thus making them catalyst sites.

Advanced battery electrolytes made with low-cost, high-throughput method

A high-throughput method for synthesizing ionic-liquid-containing electrolytes developed by Boulder Ionics Corp. (Arvada, Colo.; www.boulderionics.com) has been refined to enable its use in commercial production. Boulder Ionics had previously piloted the continuous process for producing advanced ionic-liquid (IL) electrolytes at high purity and low cost for use in next-generation batteries and ultracapacitors.

Cutting-edge electrodes allow batteries and capacitors with significantly higher energy densities than are currently available. However, the organic-solvent-based electrolytes developed to date are not suitable for the high-voltage conditions under which the next-generation electrodes operate, because of concerns over safety and electrochemical performance. Electrolytes based on ILs (salts that are molten liquids at room temperature) are nonflammable, non-volatile, have a broader operating temperature range and are electrochemically stable at high voltages.

"Existing electrolytes are simply not useful for new battery chemistries," says Tim Bradow, vice-president business development for Boulder Ionics. "Ionic-liquid-based electrolytes are known to perform well at the higher voltages and temperatures of next-generation batteries," he explains, but the barrier to the widespread adoption of this new type of electrolyte is the ability to manufacture them at low cost and high purity.

The high-throughput process developed by Boulder Ionics addresses these challenges with a microreactor approach that is tailored specifically to achieve the high (>99.9%) purities (including low halide and water levels) needed for electrochemical applications, says Boulder Ionics director of engineering Joe Poshusta. In its proprietary process, Boulder Ionics has harnessed a difficult-to-control exothermic reaction of an IL precursor without requiring large volumes of solvent.

A single production unit of the continuous microreactor process is the size of a refrigerator, Boulder Ionics says, and can produce 20 ton/yr of ILs. The company says the process can complete a synthesis of electrochemical-grade materials in 10 min that would take a week using traditional methods.

Bradow says Boulder Ionics is focusing on a narrow subset of available ILs that perform exceptionally well in battery and ultracapacitor applications. This includes the IL PYR 13 FSI (methylbutylpyrrolidinium bisfluorosulfonyl imide), and the related Li FSI salt. In addition, the company is licensing technology for other ILs from various other companies and organizations and intends to apply its high-throughput reactor methods to those ILs.

A two-step process that makes phenols from lignin

Professor Takao Masuda and colleagues at Hokkaido University (Sapporo; www.eng.hokudai.ac.jp/labo/cse), in collaboration with Idemitsu Kosan Co. (Idemitsu; Tokyo; both Japan; www.idemitsu.com), have developed a two-step process that converts wood-based lignin into phenols. They believe the achievement could lead to an environmentally friendly route for making bisphenol A and cresols for pharmaceuticals from biomass.

In the first step of the new process, lignin is first solubilized by depolymerization of lignin compounds. This is performed in an autoclave reactor using a silica-alumina catalyst in an aqueous *n*-butanol solution. The yield of lignin-based liquid product was found to be as high as 96 mol% (carbon) under optimized conditions (2 h at 300–350°C). In the second step, the lignin-based liquid is cracked in a fixed-bed reactor packed with an iron oxide catalyst (ZrO_2-Al_2O_3-FeO_x), at a pressure of 15 MPa. Yields of 14% are achieved for formation of phenols (phenol, cresol and alkyl phenols).

Bacteria and algae team-up to tackle arsenic-contaminated water

Australian researchers have developed a method of cleaning arsenic out of contaminated water by combining the effects of bacteria and microalgae. Professor Megh Mallavarapu and his team, from the Cooperative Research Center for Contamination Assessment and Remediation of the Environment (CRC CARE; www.crccare.com) and the University of South Australia (both Mawson Lakes, South Australia; www.unisa.edu.au), aimed to convert arsenic (III) into the less toxic and less soluble form, arsenic (V), making it easier to extract it from the water.

Conventional methods use chemicals to convert the arsenic, but this is expensive and often brings unwanted side effects. Bacteria have also been used, but these require carbon to grow, making the method unsustainable unless the bacteria can be continually fed. Now, the CRC CARE researchers have found species of bacteria (from soil contaminated with heavy metals) and microalgae that can sustain each other. To survive, these bacteria have developed the ability to defeat the toxicity by converting As^{+3} into As^{+5}. The scientists have also found a way to keep feeding the bacteria — the microalgae, which only need sunlight to sustain themselves, produces the carbon and oxygen needed to support the bacteria.

"However, when the bacteria break down the organic matter produced by the microalgae as well as from contaminated water, they produce CO_2, which in turn can be used to feed the microalgae. So it's a wonderful partnership," says Mallavarapu. "Once the arsenic is converted, it can be removed by absorbing it with a cheap and easily accessible material, such as coir pith (coco peat) made from coconut husks."

This graphite burner enables on-demand treatment of offgases

Offgases containing compounds of chlorine or fluorine are typically burned to enable the recovery of HCl or HF and prevent release into the environment. However, conventional combustion chambers require a long time to heat up, and thus are typically run continuously to prevent corrosion during startup or shutdown. As a result, such processes can waste a lot of energy, especially if the halide load is intermittent. This problem is now solved thanks to a new graphite porous reactor commercialized by SGL Carbon (Wiesbaden, Germany; www.sglgroup.com).

The new reactor is made from the company's Diabon graphite, which has a much smaller thermal mass than conventional burners. As a result, startup and shutdown times are only a few minutes compared to several hours needed by direct-fired combustion chambers. That means "on-demand" offgas treatment is now possible, which can reduce energy consumption by up to 50%, says the company. The compact design of the Diabon porous reactor also reduces a systems footprint by up to 60%, adds the company.

LACTIC ACID FROM PALM WASTE

(*Continued from p. 9*)

The scientists grew colonies of bacteria (found in local soil samples) in the presence of the two main sugars in EFB, xylose and glucose. Next, they selected the strain that produced the most L-lactic acid from both sugars. The most effective strain was *Bacillus coagulans JI12*, which performed the transformation at an optimal temperature of 50°C. Other bacterial species used for this purpose usually require lower temperatures. Lactic acid yields of up to 97% were achieved using the *B. coagulans JI12* bacteria with hydrolyzed EFB.

The scientists are now planning to use genetic engineering to improve the acid tolerance of the newly identified bacteria. This should allow the fermentation to be conducted at a pH lower than 6.0, reducing the amount of downstream processing required and further lowering costs.

(*Continued from p. 9*)

have a design capacity of up to 100 ton/yr of isobutene.

The new pilot plant will complement Global Bioenergies' first pilot unit in the Bazancourt-Pomacle biorefinery, close to Reims, France, which started up in June 2013 with collaboration from Arkema and the CNRS. This first pilot aims to set the stage for large-scale exploitation of the company's one-step fermentation process for making isobutene, with applications to methacrylates.

Flyash-to-litter

A process for producing cat litter that is more environmentally friendly than conventional litter has been commercialized by PURR-fect Solutions, LLC (PFS; Salt Lake City, Utah; www.purr-fectharmony.com). The process uses flyash for its base in place of bentonite, the commonly used material. The environmental advantages are that it turns unwanted waste (flyash) into a useful product and avoids the strip-mining of sodium bentonite clay, says Chett Boxley, general manager of PFS and a former researcher with Ceramatic Inc. (Salt Lake City), where the process was developed.

Flyash, a fine powder composed mainly of aluminum and silicon oxides, is pelletized by mixing it with an aqueous solution that contains an activator to promote pellet formation. The pellets are mixed with clumping agents and odor-control ingredients to obtain the final product. The litter's absorption properties are similar to those of bentonite, says Boxley, and it is cost-competitive with other commercial products. PFS expects to produce about 500,000 lb of litter this year.

Fuel cell catalyst, *sans* Pt

A team of researchers from the Max Planck Institute for Solid State Research (Stuttgart, Germany; www.fkf.mpg.de) has developed a new class of nanocatalysts for fuel cells that are cost-effective to manufacture, and whose raw materials are plentiful. The catalysts consist of organic molecules as well as iron

(*Continues on p. 12*)

This catalyst system requires significantly less palladium

A stabilized palladium catalyst system that can be used for making materials for organic solar cells and pharmaceuticals has been developed by the research groups of of Yoichi Yamada at Riken (Wako city; www.riken.jp) and Shigenori Fujikawa at the International Institute for Carbon-Neutral Energy Research (I2CNER), Kyushu University (Fukuoka City, both Japan; http://i2cner.kyushu-u.ac.jp). The catalyst features palladium nanoparticles stabilized by an array of silicon nanowires (SiNA-Pd), and is said to have the highest catalyst turnover rate (2 million) for the Mizoroki-Heck reaction — the reaction of an unsaturated halide with an alkene to form a substituted alkene.

To make the catalyst, the researchers first fabricate silicon arrays, which are composed of silicon nanowires (several to hundreds of micrometers thick) on a Si substrate. This is then dipped into an aqueous solution of a Pd^{+2} salt. The presence of a H–Si species on the substrate reduces the Pd^{+2} to form stabilized nanoparticles of Pd.

In laboratory trials, the Mizoroki-Heck reaction could effectively be carried out with four-orders of magnitude less catalyst than needed using conventional palladium catalysts.

Furthermore, the researchers demonstrated that SiNA-Pd can be used for the hydrogenation of an alkene, the hydrogenolysis of nitrobenzene, the hydrosilylation of an α,β-unsaturated ketone, and the C–H bond functionalization reactions of thiophenes and indoles.

The group is now working to enhance the stability and durability of the catalyst system, and expect that the new catalyst system will enable low-energy, low-cost and highly efficient transformations that can be applied on the industrial scale.

A new adsorbent to recover uranium and other heavy metals from wastewater

A new method for removing uranium and other heavy metals (HMs) from wastewater has been developed by researchers at the University of Eastern Finland (Joensuu; www.uef.fi). The technology has been licensed by Oy Chemec AB (Espoo, Finland; www.chemec.fi), which plans to commercialize the technology under the tradename CH Collector.

Conventional methods for removing HM from water typically require adding chemicals, either to precipitate out the metals or for adjusting the pH (as in ion-exchange processes, for instance). In contrast, no chemical dosing is required for the CH collector, which adsorbs metal ions over a very wide pH range, even in cases where the solution is rich in other ions, such as sodium, magnesium or calcium. In addition, the CH Collector allows recovery of metals in very low concentrations.

The CH Collector is an organic salt (containing C, P, O and H) belonging to the aminobiphosphate family, which is also used in osteoporosis medications. The material — developed by the research group of professor Jouko Vepsäläinen — has ion channels inside that attract and trap the metal ions directly from solution. Proper adjustment of the operating conditions enables the material to selectively remove targeted metal ions, which can then be recovered and the CH collector reused, says Lasse Moilanen, sales manager at Chemec.

Chemec is currently working in two government-sponsored Green Mining projects to develop collecting solutions for gold, talc and nickel mines, and to develop a closed-cycle process for water usage in mines. The company has also produced first batches of the CH Collector, and operates a pilot plant at its Oulu, Finland site for developing processes for customer-specific application. The technology can be used for enrichment, wastewater treatment and process waters in the mining sector, as well as the treatment of ash in boiler houses and incinerator plants, says Moilanen. ■

(*Continued from p. 11*)

and manganese on a metallic substrate. The researchers found that when Fe, Mn and the organic compound are co-deposited onto a gold substrate, a network is formed in which the metal atoms become ordered into patterns that strongly resemble the functional centers of enzymes. The scientists believe the new catalysts could be an alternative to costly Pt, currently used in fuel cells. The new class of material may also play a role in the development of new biosensors.

A new greenhouse gas?

Scientists from the Dept. of Chemistry, University of Toronto www.utoronto.ca) have discovered what appears to be a long-lived greenhouse gas (GHG) in the atmosphere — perfluorotributylamine (PFTBA), the most radiatively efficient chemical found to date.

PFTBA has been used since the mid-1900s for applications in electrical equipment, and is currently added to liquids used in electronic testing and as heat-transfer fluids. The compound does not occur naturally and there are no known processes that would destroy or remove PFTBA in the lower atmosphere, so its lifetime could be hundreds of years, says the university.

Protein purification

Therapure Biopharma Inc. (Mississauga, Ont.; www.therapurebio.com) and Upfront Chromatography A/S (Copenhagen, Denmark; www.upfront-dk.com) have entered into an agreement for Therapure to acquire the assets and associated business related to human plasma fractionation from Upfront. Upfront has developed a proprietary protein-purification technology, based on its expanded bed adsorption (EBA) chromatography, which uses an upward flow of liquid that fluidizes the adsorbent medium; this allows particulate material to flow through the column without clogging the system.

Upfront divested its pharmaceutical business in 2010 to DSM Biologics, and is focusing on its BioMine business line — technology for extracting food-grade proteins from waste streams in the food-processing industry. ❑

ThyssenKrupp Uhde

MAKING PROPYLENE ‘ON-PURPOSE’

FIGURE 1. The EPP PDH plant in Egypt is the first in the world to feature propane oxydehydrogenation, using technology from ThyssenKrupp Uhde

The shift to ethane cracking in the U.S., and the availability of low-cost LPG is accelerating the construction of propane dehydrogenation plants

Propylene — one of the most important petrochemical feedstocks — has traditionally been supplied, together with ethylene, primarily from naphtha crackers. The recent exploitation of shale gas in North America is causing a shift to ethane cracking as a source for ethylene (*Chem. Eng*., October 2012, pp. 17–19). As a result, petrochemical producers are scrambling to find alternative sources for C3 and C4 olefins. This is good news for companies offering on-purpose propylene technology, such as propane dehydrogenation (PDH) process technology.

“The breathtaking development of the shale gas market in the U.S., which is flooding the market with low-cost NGL [natural gas liquid] feedstock and driving the ethylene industry further away from naphtha toward ethane feedstock, is putting pressure on the propylene market and making PDH highly competitive in the U.S.,” says Max Heinritz-Adrian, head of Gas Technologies Division, ThyssenKrupp Uhde GmbH (Dortmund; www.thyssenkrupp-uhde.eu), a company of ThyssenKrupp Industrial Solutions AG (Hamburg, both Germany). PDH, besides coal-to-olefins, also plays a big role in China, says Heinritz-Adrian. “China is pushing PDH based on imported LPG [liquefied petroleum gas] as a means of reducing its propylene import dependency, as well as further supporting its growth program in the downstream petrochemical industry,” he says.

According to a 2012 study by IHS Chemical Market Associates, Inc. (CMAI), on-purpose propylene technologies — including PDH, metathesis and methanol-to-olefins — have a market share of 12–14% of global propylene production, and this share is expected to grow to over 20% in the near future. The following focuses on PDH technology as a source of propylene.

A surge in PDH plants

Within the the last few years, CB&I (The Hague, the Netherlands; www.cbi.com) and its partner Clariant (Muttenz, Switzerland; www.clariant.com) have seen very strong growth for the PDH business. Over the last four years, 18 Catofin and Catadiene (for butadiene) plants have been licensed. Recent highlights include a 750,000-ton/yr PDH plant for Enterprise, located in Houston and scheduled to start up in 2015; a 600,000-ton/yr PDH plant for SK Gas, located in Korea and slated to come on stream in 2016; and the successful startup of the first PDH plant in China, a 600,000-ton/yr Catofin plant located in Tianjin.

Over the last three years, UOP LLC (Des Plaines, Ill.; www.uop.com), a Honeywell company, has licensed Oleflex technology to 19 Chinese producers. Since the technology was first commercialized in 1990, UOP has commissioned nine C3 Oleflex units for on-purpose propylene production and six C4 Oleflex units, four of which are in North America, for on-purpose isobutylene production. Among the most recent North-American projects is the first in Canada — a 1-billion lb/yr PDH unit for Williams (Tulsa, Okla.), which was announced in March 2013. The Williams PDH facility will be located in Alberta, Canada, and will convert propane recovered from oil-sands offgas into polymer-grade propylene using UOP’s C3 Oleflex technology. And in May 2013, UOP was selected for what is claimed to be the world’s largest on-purpose propylene production facility — Ascend Performance Materials Operations LLC will use UOP’s C3 Oleflex technology to produce more than 1-million metric tons (m.t.) per year of propylene when the facility starts up in 2015 on the U.S. Gulf Coast.

In 2010, ThyssenKrupp Uhde started up the third plant to utilize its STAR (Steam Active Reforming) technology. The PDH plant is part of a PDH/PP (polypropylene) complex of Egyptian Propylene & Polypropylene Co. (EPP) in Port

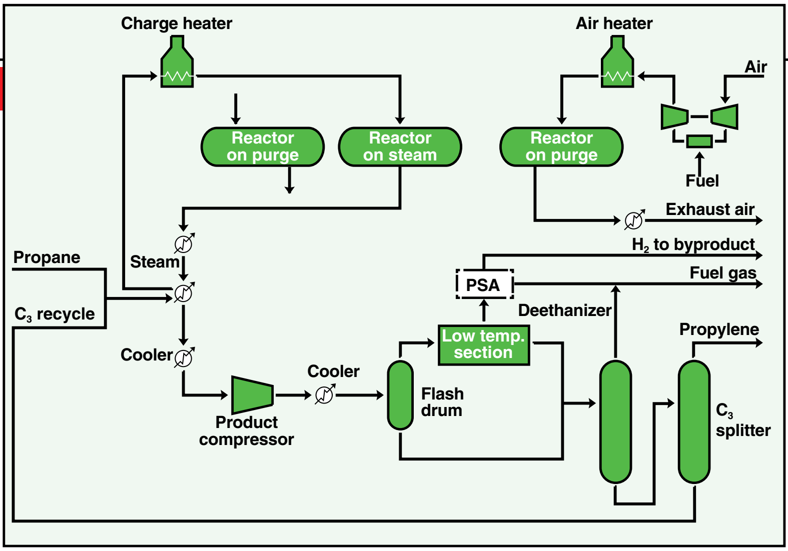


FIGURE 2. This flowsheet shows the Catofin dehydrogenation process for the production of propylene (PSA = pressure swing adsorption)

Source: CB&I

Said, Egypt (Figure 1), and has a capacity of 350,000 m.t./yr of polymer-grade propylene.

Currently, ThyssenKrupp Uhde is executing two additional projects for its fourth and fifth STAR process plants for undisclosed clients in the MENA (Middle East & Northern Africa) region (each PDH plant has a capacity of 450,000 m.t./yr of polymer-grade propylene), as well as for a sixth STAR process plant in Texas, with a capacity on the order of 545,000 m.t./yr of polymer-grade propylene.

Meanwhile, BASF SE (Ludwigshafen; www.basf.com) and Linde (Munich, both Germany; www.linde.com) are also seeing an increased interest in the jointly developed BASF/Linde PDH technology. In the past year, increased interest and an increasing number of inquiries have been observed, not only from the U.S., but also from Asia, says BASF.

PDH catalysts

Catalyst suppliers are also increasing production in order to be able to supply new PDH plants. Last October, Clariant expanded its Houdry PDH catalyst capacity at its Louisville, Ky. plant. The double-digit million Swiss-francs debottlenecking investment aims to support the increasing demand for the catalysts, driven mainly by shale-gas development. "Increasing production capacity for our proprietary, high-performance Houdry catalysts is an important part of Clariant's growth strategy to capture opportunities driven by shale-gas development, which increases significant need for on-purpose olefin production," says Stefan Heuser, senior vice president, head of BU catalysts at Clariant.

Also last October, Honeywell announced plans to establish a new manufacturing campus in Zhangjiagang, China to support growing demand in Asia for energy technology and advanced materials produced by its Performance Materials and Technologies (PMT; Morristown, N.J.; www.honeywell.com) business. The initial phase of the investment will include catalysts and adsorbents production capacity for Honeywell UOP, part of which will be a production facility for advanced catalysts for the UOP Oleflex process technology.

Process technology

PDH is the catalytic conversion of propane into propylene and hydrogen. The following presents a few of the commercially available technologies for performing this endothermic reaction.

Catofin. The Catofin process (Figure 2) uses fixed-bed reactors with a chromium-oxide-based catalyst developed by Clariant (formerly Süd-Chemie). The continuous process operates with cyclic reactor operation reheat/regeneration (for more information, see also the Technology Profile on p. 27). Operating conditions are selected to optimize the relationship between conversion, selectivity and energy consumption. The overall selectivity of propane to propylene is greater than 86 mol%. Capacities of over 850,000 ton/yr in a single train are possible with Catofin technology, allowing significant use of economy of scale. Catofin technology is the most reliable and robust process proven commercially showing the highest on stream factor in the market, says CB&I and Clariant.

Recently, the process energy consumption has been further reduced via a patented low-energy scheme. Another recent development is the introduction of a so-called heat-generating material (HGM) into the reactor system.

Since heat input to the catalyst is the limiting factor for the dehydrogenation reaction, HGM — which consists of a metal oxide on a proprietary support — chemically generates heat in situ, while remaining inactive to the feed and product, and improving the overall heat balances of the system.

In 2012, the Catofin/HGM concept was first proven on the commercial scale in an industrial Catofin plant. HGM significantly increases the olefin production rate by boosting the olefin selectivity and at the same time lowering the energy consumption, says Clariant.

Oleflex. First commercialized in 1990, Honeywell's UOP Oleflex process uses a fully recyclable platinum alumina-based catalyst system (for a flowsheet and more process details, see Technology Profile, *Chem. Eng.* February 2013, p. 33). Compared with competing PDH processes, UOP Oleflex technology provides the lowest cash cost of production, the highest return on investment and the smallest environmental footprint, says Pete Piotrowski, senior vice president and general manager of UOP's Process Technology and Equipment business unit.

BASF/Linde. The BASF/Linde dehydrogenation process section is derived from Linde's proven steam-reforming technology, whereas the backend of the process (product separation) is based on Linde's established ethylene technology. The latest dehydrogenation catalyst development at BASF focuses on a supported and steam-resistant Pt-Sn catalyst, which yields excellent selectivity and activity. The fixed-bed reformer-type reactor is operated at 550–650°C and regeneration is done periodically in situ using air.

Under isothermal operation, propane selectivities of over 90% are achieved, says BASF. Due to reduced coke formation and low catalyst deactivation, catalyst lifetimes of over two years are typically expected. High conversion rates and the simple fixed-bed reactor design allow for smaller equipment and thus low investment. In addition, operation above atmospheric pressure provides higher safety standards compared to other technologies, says BASF.

STAR. Since ThyssenKrupp Uhde acquired the STAR process and STAR catalyst technology from Phillips Petroleum Co. in 1999, the company enhanced the process by adding an oxydehydrogenation section from downstream the conventional reactor (Figure 3). It is said to be the only propane/butane dehydrogenation technology that can use the advantages of oxydehydrogenation.

In oxydehydrogenation, oxygen is introduced into the reactor, where it reacts with some of the H_2 product to form H_2O. This shifts the equilibrium of the dehydrogenation reaction to the right, thereby increasing the conversion. Also, the formation of H_2O is an exothermic reaction, so it supplies additional heat for the endothermic dehydrogenation reaction.

The STAR catalyst is based on a zinc and calcium aluminate support that, impregnated with various metals, has excellent dehydrogenation properties with high selectivity at near equilibrium conversion and is versatile in its application. The catalyst is extremely stable in the presence of steam at high temperatures, which provides unique advantages to the process, says ThyssenKrupp Uhde. It has been commercially proven, is very robust and has shown lifetimes of more than five years, which results in low cost for catalyst consumption, says the company.

The reactor is a fixed-bed steam-reformer-type reactor, a technology in which ThyssenKrupp Uhde has vast experience, with more than 70 reformers and more than 40 secondary reformers or oxyreactors with a similar design, says the company.

Competing technologies operate close to atmospheric pressure or even lower (under vacuum) to ob-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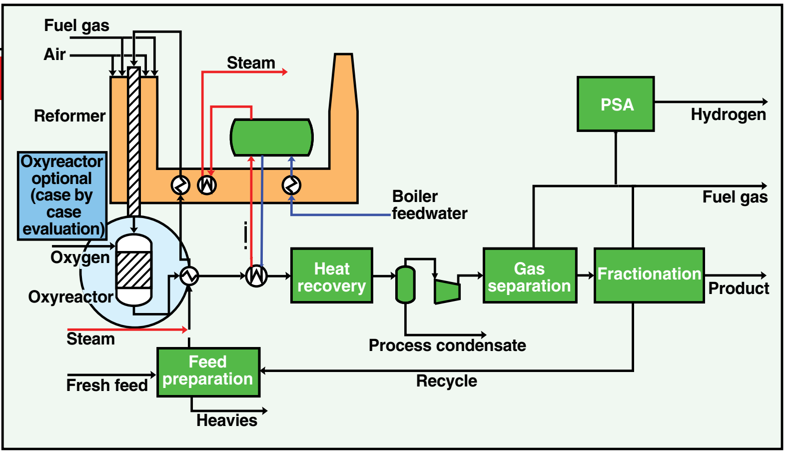

FIGURE 3. ThyssenKrupp Uhde's STAR process utilizes a reformer reactor, with an option for oxydehydrogenation

tain acceptable yields. The STAR process has the highest space-time yields of all PDH technologies, and operates at a reactor exit pressure of approximately 5.8 bar(a), thereby allowing higher compressor suction pressures, which significantly saves capital and operating expenses (CAPEX and OPEX) on raw-gas compression.

Furthermore, compared to other technologies, the STAR process operates at rather mild process temperatures (below 600°C), above which coke formation is more severe and leads to higher de-activation rates of the catalyst. Therefore the formation of unwanted side products, which require further treatment steps in the downstream product separation, are minimized, says the company.

ThyssenKrupp Uhde works continuously to further improve its STAR process technology, both with regard to the process itself and the catalyst, says ThyssenKrupp Uhde's Heinritz-Adrian. "For this we operate a dedicated pilot plant and catalyst test facility at our research center in Ennigerloh, Germany, and cooperate with renowned partners on catalyst development."

In addition, ThyssenKrupp Uhde has further optimized its downstream processing of raw reactor product, improving propylene recovery and further decreasing CAPEX and OPEX, says Heinritz-Adrian. "The STAR process is characterized by excellent robustness, ease of operation, and simple and low-cost maintenance, providing substantial benefits to the licensees of our technology." ■

Gerald Ondrey

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BUILDING A BETTER WEIGHING INSTRUMENT

Modern technologies provide solutions for common weighing challenges


Cardinal Detecto Scale Manufacturing

FIGURE 1. Cardinal Scale offers the Model 201 weight transmitter as an instrument for process-control-based static- and dynamic-weighing applications

Like most of the world, weighing instrumentation has gone digital and gotten connected. Not only do today's scales, weight transmitters, check weighers, and other weighing equipment include more modern technological advances, but the up-to-date improvements also provide contemporary solutions for a lot of old-school weighing challenges.

Going digital

While the main goals of weighing operations in the chemical process industries (CPI) — typically either weighing material for batching, filling, blending or portioning applications or for quality control purposes to ensure that the right amount of material is being shipped out the door — haven't changed, advances in digital and networking technology have. And these changes are having a positive impact on today's weighing equipment.

"During the last few years with the rise of the digital world, networking and servers, there have been requirements and requests from our customers to digitally automate and connect as much as is possible," says Fred Cox, vice president of sales with Cardinal Detecto Scale Manufacturing Co. (Webb City, Mo.; www.cardet.com).

Connectivity usually refers to interfacing in one of two ways, says Steve Wise, marketing programs manager with Mettler Toledo (Columbus, Ohio; www.mt.com). One is the connection of a sensor to a programmable logic controller (PLC) for realtime control of the weighing process. An example of this might be connecting scale sensors to the PLC to automate a batching process based on weight.

The benefits here include allowing the scale to act as a sensor (almost like a temperature sensor), and using it as a springboard to control and send commands to the PLC itself. "The interface almost provides realtime, high-speed updates directly to the PLC so the operators can make decisions about the process as it's running," explains Wise.

The other type of connectivity provides transactional information. "This might include sending data about the batched amount with time and date information to a PC," Wise explains.

"Production managers need to know how much material they used, how long it is taking them to do batches, and other process information," says Wise. "By sending all this information to a database where it can be stored and analyzed, huge benefits, in the form of efficiency gains can be found."

For these reasons, new weighing instruments that can provide this kind of connectivity are beginning to find their way into chemical processing facilities. Mettler Toledo's IND780 weighing terminals are a prime example. These instruments provide connectivity for multiple sensor technologies, networking and PLCs. The communication capabilities range from basic serial protocols up to custom PLC data templates. The units help maximize productivity in the following ways: by optimizing the amount of visible information on the LCD display; by configuring up to four concurrent scales and a metrologically approved sum scale and showing one or more of these on the display at the same time; and by improving the speed and accuracy of manual or semi-automatic operations with a feature that offers three display models to graphically show weigh status to the target.

Cardinal Scale offers the Model 201 (Figure 1) weight transmitter as an instrument for process-control-based static- and dynamic-weighing applications. The 201 can power up to eight load cells and offers sample rates of up to 200 samples per second. The transmitter uses standard communication protocols, including serial interface RS232/RS485, mini USB-B, analog (0–10 V or 4–20 mA), Ethernet TCP/IP, EIP and Modbus TCP, making it easy to connect to a PC, PLC or other smart devices. Four programmable digital inputs and outputs increase the flexibility.

"Years ago, no one was interested in realtime data or analysis of their weighing operations, but as chemical processors were forced by economy and competition to improve

Thompson Scale

FIGURE 2. Model 4693 filler controller from Thompson Scale offers (among other features) multiple product recipes and optional statistical analysis packages

Scaletron Industries

FIGURE 3. This image shows Scaletron's Model 4042 spill containment scale and the available controllers, including Model 1099 Chemical Process Controller (the controller on the right)

performance, they needed a way to look at trends and analyze this type of information on a regular basis," says Alan Vaught, vice president of operations and co-owner of Thompson Scale Co (Houston; www.thompsonscale.com). "In-depth analysis can be difficult with fewer people doing more tasks. So, having connectivity to the scale as a way to manage the data is extremely important in today's competitive process environments because it allows operators or managers to change recipe information, including target weight and reject limits, and to collect, store and analyze data as a means to improve performance."

Vaught says he sees more interest today in data and process control than in pure quality control of the product weight itself. "Our customers are now driven to control the process and attack the root cause of the problem, as opposed to just getting rid of bags that are out of spec. While quality control is the holy grail of weighing operations, they need a window into the process itself to get the accuracy required for tip-top quality control. Connectivity between the scale and the PLC or PC is the way to do that," explains Vaught.

Improving accuracy

Vaught says that in the past, the biggest concern of the chemical processor or packager was producing underweight packages, but today there are different concerns. "Our customers are more concerned with generating packages that are on target — none can be under- or overweight — because the end user who is buying the package is likely mixing it directly into their own batching process," he says. "If you sell them a bag that is marked as 25 kg, it needs to be 25 kg within very tight tolerances. Overweight product can affect the quality of their process and end product as much as if it were underweight."

This push for accuracy within tight tolerances is driving the manufacturers of weighing equipment to develop new products specifically designed to improve accuracy of the process, while also providing the connectivity needed to see into the process.

Thompson Scale, for example, offers two models of integrated filler controllers, designed for use on virtually any type of filler system. Model 4693 filler controller (Figure 2) offers multiple product recipes and optional statistical analysis packages. Model 5511 offers a color touchscreen, multiple recipes, native Ethernet TCP/IP and serial ports, and the ability to integrate with data logging and reporting software. Both units offer automatic set point controls, automatic tracking and correction of weight variance, and easy-to-follow prompts on the screen to help minimize operator mistakes and improve efficiencies.

Another common accuracy issue, according to Nicole Gibson, project engineer with Scaletron Industries, Ltd. (Plumsteadville, Pa.; www.scaletronscales.com), is the weighing of large capacities. "When dealing with hundreds or thousands of pounds, accuracy becomes challenge, as far as the base design and the readout of the indicator. So we have recently developed a digital design in which the indicators are much more accurate than the old analog style but still offer the output that our customers require."

The company's Model 1099 Chemical Process Controller (Figure 3) is based upon this design. It provides accurate scale weights and automated use reports, while offering the ability to monitor up to 16 load cells. It is capable of operating drum, platform, and ton scales in the same system and has an indicator that can display gross weight, net weight, daily usage, amount used, days until empty and feedrate.

Digital load cells and the connectivity they provide, according to Wise, also help improve accuracy in weighing operations. Instead of sending out analog voltage signals and then reading those signals back, a digital load cell does analog-to-digital conversion right in the load cell and is connected back to the weighing terminal via the communications network.

"The benefit here is that each individual load cell is read separately, so if you have a tank with four legs and put a load cell under each leg, an analog system would read those as one unit, but a digital system reads each load cell individually," explains Wise. "This allows processors to see if any one of those load cells starts to drift or have damage. Each can be monitored individually and an alert can be sent if something goes wrong. It allows processors to be proactive about maintenance and also to catch any errors that might be happening in the scale."

To this end, Mettler Toledo released the Pinmount PDX load cell (Figure 4), which allows true predictive diagnostics of each individual load cell. Its built-in predictive diagnostics system constantly monitors

Mettler Toledo
PDX

FIGURE 4. Mettler Toledo's Pinmount PDX load cell allows true predictive diagnostics of each individual load cell

the load cell and alerts the supervisor if a potential problem arises. The microprocessor inside each load cell continually adjusts the weight signal to compensate for environmental factors. It provides accurate weighing regardless of the effects of temperature, linearity, hysteresis and creep.

Reliability and safety

In the CPI, reliability and safety are two of the biggest concerns when it comes to weighing equipment. The first step to ensuring that the weighing equipment is going to operate properly and safely in a particular chemical environment is to be careful when selecting equipment.

Cal Schumacher, regional sales representative with Rice Lake Weighing Systems (Rice Lake, Wis.; www.ricelake.com), says problems with reliability in a given chemical environment often arise because the buyer of the scale doesn't know what type of equipment to use. "We always start by asking them what is the total capacity, including the vessel that you need to place on load cells, and what sensitivity do you require." From there, he says, it should be determined whether a legal-for-trade (NTEP-approved) product is required. And finally, the operating environment is crucial. "Is it explosive or are there volatile chemicals or fumes? Is the area wet or dry? Is it getting washed down? We need to ask these questions right off the bat so we can supply

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the right product," says Schumacher. "That's the first step in getting equipment that is both reliable and safe in an application."

"As a general rule, when placing load cells and mounts into any chemical process environment, it is always wise to use stainless-steel mounts and stainless-steel hermetically sealed load cells," says Schumacher. "Our RL1600 HE weigh modules would be an excellent choice. Regarding indicator choices, if a simple weight is all that is required, I recommend using an indicator in a stainless-steel or chemical-resistant fiberglass enclosure. For more involved process-control systems I would recommend our 920i series of indicators [Figure 5]."

In chemical weighing environments, meeting safety standards for containment and management of chemicals and spills is another major issue. "With more and more OSHA, EPA and local requirements regarding spills, spill containment capability on scales is becoming more vital than ever, so we offer spill containment scales that can both survive and contain a spill," says Gibson.

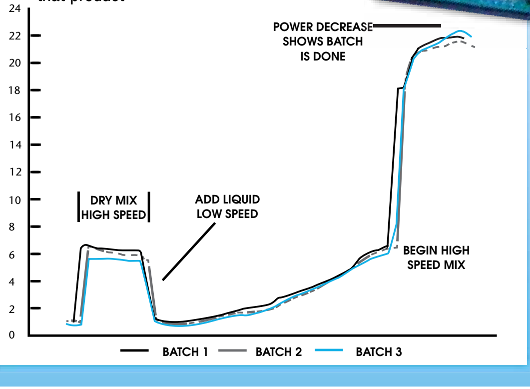
The Model 4042WB spill containment scale with bladder accurately displays the weight of the net remaining chemical that has not been dispensed and meets secondary spill containment requirements set forth by EPA, OSHA and local agencies. The rugged steel construction is protected by a corrosion-resistant finish with a polyethylene containment basin. The four-load cell design means the load can be placed anywhere on the containment platform without needing to be leveled. Additionally, the load cells are mounted outside of the spill-containment basin to eliminate damage due to chemical spills.

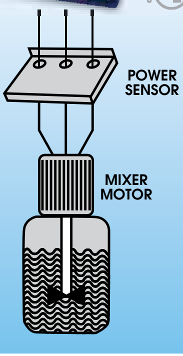
Rice Lake Weighing Systems

FIGURE 5. If simple weight is all that is required, an indicator in a stainless-steel or chemical-resistant fiberglass enclosure can be used. For more involved process-control systems, the 920i series of indicators from Rice Lake will fit the bill

Digital technology and networking connectivity has not only taken weighing equipment into the modern age, but it has also helped solve a lot of age-old weighing issues for CPI processors. Accuracy, reliability and safety have all been improved due to technological advances in today's weighing equipment. ■

Joy LePree





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Dow Corning

A new polyethylene grade for large-width films

The new Supertough 22ST05 metallocene polyethylene grade (photo) is aimed at the industrial films sector, embracing the need for easy-to-process, high-performance downgauging film solutions. Supertough 22ST05 films feature excellent bubble stability and mechanical properties that give them the potential to downgauge by up to 25%, allowing for the development of large-width films, says the manufacturer. Large-width films are important in agriculture and transportation applications, among others. — *Total Refining & Chemicals, Brussels, Belgium*
www.totalrefiningchemicals.com

This material is an alternative to glass and polycarbonate

Akestra is a new high-performance plastic material whose properties make it a viable alternative to polycarbonate, polystyrene and glass. Featuring a high glass-transition temperature, clarity, heat resistance, high melt strength and amorphous characteristics, this durable material can be blended with other plastics to improve their properties. In packaging applications, Akestra can be used in either reusable or disposable products. The high melt strength of Akestra makes it particularly suitable for extrusion blow-molding and extrusion foaming processes. In combination with polyethylene terephthalate (PET), it creates a fine cell structure, resulting in desirable mechanical properties for structural and packaging foam applications. — *Perstorp Holding AB, Perstorp, Sweden*
www.perstorp.com

This moldable optical silicone will not degrade in high heat

MS-2002 Moldable White Reflector Silicone (photo) is a highly reflective optical-grade white material that is intended for light-emitting diode (LED) lamp and luminaire applications. MS-2002 material targets a reflectivity as high as 98%, which boosts light output from LED devices, improves energy efficiency and prolongs device reliability, says the company. This material also delivers mechanical, thermal and optical stability at temperatures exceeding 150°C. Unlike conventional LED materials, such as epoxies, polycarbonates and acrylics, MS-2002 silicone is said to retain its properties and performance over the lifetime of a device without physical degradation. This product also does not require the additional mixture of liquid silicone rubber or color pigmentation. — *Dow Corning, Midland, Mich.*
www.dowcorning.com

Use these retaining compounds on contaminated surfaces

The newly enhanced Loctite anaerobic retaining compounds (photo) allow primerless performance on oily or contaminated surfaces, even at very high operating temperatures. Used in combination with interference fits to secure bearings, bushings, gears and cylindrical assemblies into housings or shafts, the Loctite line of products allow for high load transmission, relaxed machine tolerances and a general reduction in assembly size. Loctite 638 is a general-purpose retaining compound recommended for press fits that will need subsequent disassembly. Designed for use on loose-fitting parts, this high-strength adhesive resists temperatures to 175°C and can be used on applications with gaps approaching 0.25 mm. Loctite 648 is recommended for continuous working temperatures to 180°C. This general-purpose retaining adhesive fixes in five minutes with full cure in 24 hours and is designed for use on close-fitting parts. The high-strength formulation bonds well to stainless-steel press and interference fits, and fills gaps to 0.15 mm. Loctite 680 is a low-viscosity, high-strength retaining adhesive for use on slip-fitted parts with gaps as large as 0.38 mm. Both Loctite 648 and 680 are certified to ANSI/NSF Standard 61 for use in potable water systems. — *Henkel Corp., Rocky Hill, Conn.*
www.henkelna.com

A new polypropylene resin with a high melt flowrate

This company's new clarified random copolymer 80R90CD polypropylene (PP) resin delivers stiffness, desirable impact performance and clarity. Its lower processing temperatures, when compared to other similar materials, allow for simplified mold design, extended tool and equipment lifetime and decreased energy usage. The high melt flowrate of 80R90CD clarified PP reduces maximum molding pressure, allowing lower-tonnage machines to be used and contributing to longer

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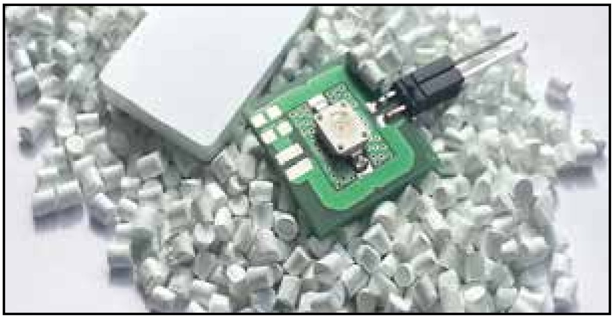
Isola Group S.a.r.l.

Lehvoss North America



tool life and reduced maintenance. From a design standpoint, higher flow — together with the stiffness and impact of this new grade — makes it appropriate for thin-wall injection molding. Higher flow also makes it easier to design parts because there are fewer flow-related challenges to overcome compared to conventional materials. Target applications for the new grade include food storage containers, food packaging, housewares and household storage items. — *Propilco, S.A., Bogotá, Colombia*
www.propilco.com.co

Use these thermally conductive materials with LEDs

New thermally conductive Luvocom compounds (photo) are designed to meet specific requirements for LED applications. These materials are characterized by a thermal conductivity ranging from 0.6 to 1.5 W/mK, are electrically insulative, and have a tensile strength of up to 8,000 psi (55 MPa) and an impact strength up to 14 ft-lb/in.^{2} (29 kJ/m^2). Typical Luvocom materials use PET and aliphatic polyamide (PA 6) as base polymers, giving the compounds processing characteristics which enable injection molding of complex geometries and thin wall sections, says the manufcaturer. — *Lehvoss North America LLC, Pawcatuck, Conn.*
www.lehvossllc.com

This corrosion-resistant water-based coating is low in VOCs

This newly released Teflon industrial coating is water-based, easy to use and is very corrosion resistant — up to 3,000 salt-spray hours. Specifically engineered for coating offshore, chemical processing and water-treatment fasteners, the new coating is targeted for applications demanding high levels of corrosion resistance, anti-galling and dry lubrication. This coating is also very low in volatile organic compounds (VOCs). Coatings are available in blue and red, with yellow and black options being added in the near future. — *DuPont, Wilmington, Del.*
www.dupont.com

This microwave laminate compound exhibits high stability

Astra is a new compound with a low-loss dielectric constant for radio-frequency (RF) and microwave designs. The compound's lead-free laminate materials exhibit electric properties that are constant over a broad frequency and temperature range, for simple processing. Featuring a dielectric constant that is stable between –55 and 125°C and a low dissipation factor, Astra can be processed at lower temperatures (under 200°C) than competitive products, making it a cost-effective alternative to other commercial microwave laminate products, such as PTFE. Key applications include long antennas and radar applications for automobiles (photo), such as adaptive cruise control, pre-crash, and blind-spot detection. — *Isola Group S.a.r.l., Chandler, Ariz.*
www.isola-group.com

This material improves industrial ceramics' performance

This company has produced a new 3YSZ (3-mol% yttria-stabilized zirconia) material for high-strength industrial ceramic applications, such as valve components and process equipment. Manufactured to ensure retention of an intrinsic nanostructure, this product's high density and chemical homogeneity give ceramics increased bonding strength, thermal stability and fracture resistance. Featuring an expansion coefficient similar to that of steel, 3YSZ materials are corrosion-resistant and can be supplied in application-specific forms — as a spray-dried granulated power (with or without binder), suspension or slurry. These materials' inherent nanostructure increases chemical activity, allowing for ceramics to be processed at lower temperatures. — *Innovnano, Porto Salvo, Portugal*
www.innovnano-materials.com

Enhance thermoplastics with these custom flame retardants

Exolit OP flame retardant solutions support high-temperature thermoplastics in the electrical and electronic industries. Exolit OP 1400 is formulated for polyamides while Exolit OP 1260 is compatible with polyesters. These new compounds are designed to improve fire safety, along with processing and mechanical performance of these thermoplastic families. According to the company, these formulations can be customized to the fire protection challenges of specific thermoplastics. Exolit OP 1400's thermal stability helps to avoid issues, such as polymer degradation, formation of decompositions products and discoloration. Exolit OP 1260's synergistic blend addresses fire safety and enhances melt flow, without the need for additional flame-retardant additives. — *Clariant, Muttenz, Switzerland*
www.clariant.com ■

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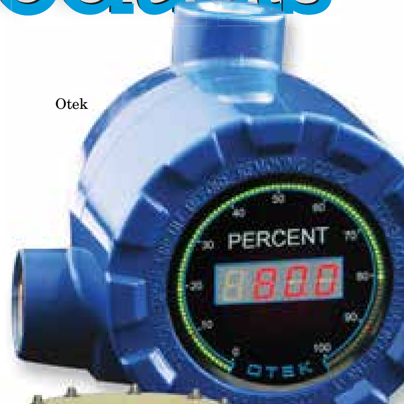
JANUARY New Products


Martin Engineering


Otek

A digital bar-meter with low signal-power requirements

The LPD-X (photo) is a loop-powered, explosion-proof bar-meter that is designed for hazardous locations. Requiring less than 50 MW of signal power, the LPD-X features a 300-deg auto-tricolor, 51-segment bar, a four-digit display, an isolated serial input/output, an alarm with four setpoints and loop-failure detection functionality. The meter can be mounted on a panel, wall or ¾-NPT connection. The meter's display screen is made of ultraviolet (UV) coated glass. — *Otek Corp., Tucson, Ariz.*
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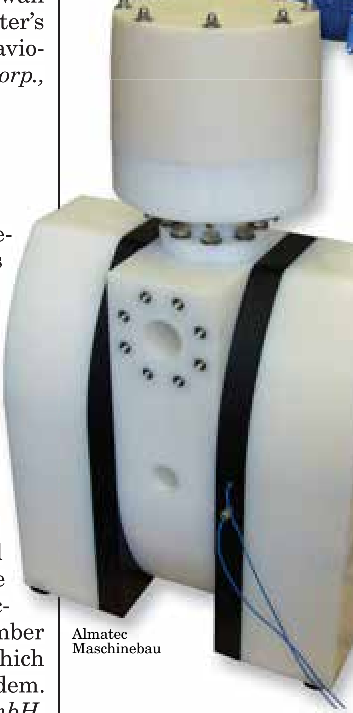

Almatec Maschinebau

This pump's plastic build resists abrasion

The E80 air-operated double-diaphragm pump (photo) is constructed with polyethylene, making it resistant to abrasive materials. Equipped with a 3-in. nominal connection diameter and a maximum capacity of 210 gal/min, these plastic-bodied pumps boast dry-run and self-priming capabilities. Low maintenance, with no rotating parts or shaft seals, the E80 is designed with integrated flanged connections to ensure stability and leakage protection. An optional barrier-chamber system is also available, which has two diaphragms in tandem. — *Almatec Maschinebau GmbH, Kamp-Lintfort, Germany*
www.almatec.de

This tool cleans vessels without confined-space entry

The Heavy Duty Whip (photo) is a portable, remote-controlled solution for blocked vessels and plugged discharge chutes. The Heavy Duty Whip can be lowered into storage vessels through a manhole opening, allowing it to address blockages without the need for confined-space entry by personnel. Powered by compressed air, this tool uses a modular boom arrangement that extends from 2 to 8.5 m and can clean vessels up to 18 m in diameter and 68.5 m tall from a single central opening of just 450 mm. The Heavy Duty Whip can also be equipped with a variety of flails and cutting edges to knock down accumulated material without damaging storage vessels. Abrasion-resistant steel chain is best suited for most applications, with non-sparking brass chains available for combustible materials. — *Martin Engineering, Neponset, Ill.*
www.martin-eng.com

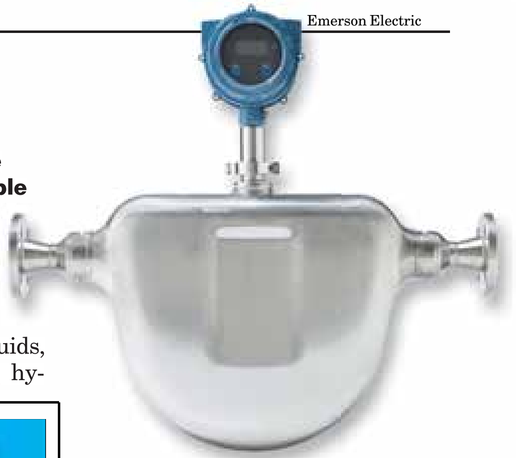

Clark Solutions

These switches experience low corrosion and degradation

The Series 605 Differential Pressure Switch (photo) is designed for use with air and non-corrosive gases in applications such as interlock systems, fume hoods and pressure control in gas-fired heating systems. These switches feature a unique trapezoidal-bead diaphragm design, which provides desirable contact release and high levels of accuracy. Standard on these switches is a self-cleaning contact design, minimizing their

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

susceptibility to contact-point corrosion or degradation. Integrated cable-strain relief is also standard, assuring connectivity. Series 605 Switches can be installed either vertically or horizontally without impacting performance. — *Clark Solutions, Hudson, Mass.*
www.clarksol.com


Emerson Electric

Use this density meter where process conditions are variable
The Micro Motion Compact Density Meter (photo) is a multivariable density meter designed to alleviate the measurement challenges associated with the transfer of aggressive process fluids, including alcohols and refined hydrocarbons. Combining a high-speed signal-processing technology with an optimized meter design, this meter measures both the fluid temperature and its own meter-case temperature, minimizing errors due to changes in environmental conditions. The meter also features fluid flowrate indication, allowing users to quickly diagnose installation problems, such as product buildup for blockages. Calibrated over a wide range of combined temperatures and pressures, these meters are capable of accurate operation even in very harsh environments with varying process conditions. The transmitter module can output sensor data in multiple formats. — *Emerson Electric Co., St. Louis, Mo.*
www.emerson.com

This spectrometer system can incorporate up to eight channels
The CompactSpec II spectrometer system is designed for process control in harsh environments. Encased within a protective stainless-steel housing, the system features a xenon flash lamp that provides high-intensity broadband light, with a separate reference channel allowing for realtime compensation for lamp variability, giving drift-free operation. The lamp's long lifetime decreases maintenance requirements. The systems can cover a wavelength range from 190 to 2,150 nm, and up to eight channels can be incorporated into one system. Probes for inline measurements (operating at up to 300°C and 300 bars) in pipes and reactors are available. — *Tec5USA, Inc., Plainview, N.Y.*
www.tec5USA.com ■

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CHEMICAL ENGINEERING
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Department Editor: Scott Jenkins

Dust Hazards

Dust is a critical consideration in the chemical process industries (CPI) from both a process safety standpoint — as a potential fire and explosion hazard — and from an occupational safety standpoint — as a potential worker exposure hazard. Reinforcing basic concepts about dust behavior and properties can help reduce the risks.

HEALTH HAZARDS

Airborne particles are solids suspended in the air, usually formed by disintegrating processes like crushing, grinding, blasting, drilling and others. Their particle sizes determine, to a large extent, their behavior when mixed with air. Particles larger than 100 microns (μm) fall out quickly, while particles in the range between 1 to 100 μm settle out slowly, and those smaller than 1 μm take days or years to settle out in a quiet atmosphere, and may never settle in a turbulent atmosphere. Table 1 presents the typical particle size ranges for a small sampling of materials for comparison.

Assessing health hazards

Three main factors are used for assessing the potential health hazards of inhaled dusts: the chemical composition of the dust; the particle size and shape; and the exposure concentration and duration. The three elements are interrelated in determining how inhaled dust could affect workers, because they govern the quantity of material that enters the body, the location within the body where it ends up, and what effects it might have.

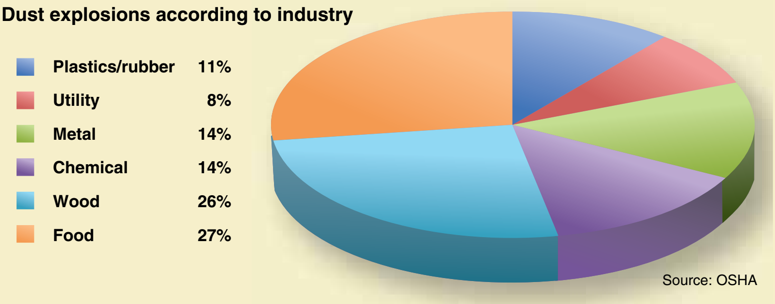
In occupational safety contexts, dusts are often classified into categories such as inhalable dusts, which the U.S. Environmental Protection Agency (EPA) describes as the fraction of dust that can enter the body but that is trapped by the nose, throat and upper respiratory system. Respirable dusts refer to particles that are small enough to penetrate deep into the lungs and are beyond the body's natural clearance mechanisms of cilia and mucous.

The total allowable particle concentration from building materials, combustion products, mineral fibers and synthetic fibers (particles less than 10 μm) is specified by the EPA as 50 μg/m^3 allowable exposure per day over the course of one year or 150 μg/m^3 allowable exposure over 24 hours.

EXPLOSION HAZARDS

In addition to health hazards, dust presents critical explosion risks in CPI environments (Figure 1). A number of conditions must be met in order for a dust explosion to occur when a combustible dust is suspended in air and ignited.

- The dust must be combustible and release enough heat when it burns to sustain a fire
- The dust must be capable of being suspended in air
- The dust must have a particle size capable of spreading a flame
- The concentration of the dust suspension must be within a range that can explode
- An ignition source must be in contact with the dust suspension
- The atmosphere must contain sufficient oxygen to support and sustain combustion



Source: OSHA

FIGURE 1. Dust explosions can and do occur in a variety of industries

Dust pentagon. A play on the better known term "fire triangle," the dust pentagon refers to the five elements required for a dust explosion. In addition to the fuel to burn, the oxygen and an ignition source (heat, spark, and so on) common to all fires, dust explosions require two additional elements: dispersion of dust particles in the correct concentration and confinement of the dust cloud in an enclosed or limited space. A so-called "optimum cloud density" means that a sufficient distance between the particles exists to allow access of oxygen around the particles, but the particles are close enough so that the heat of one ignited particle can initiate reactions in nearby particles.

Minimum ignition energy (MIE). MIE is the minimum energy of an electrical spark, which under defined conditions, is able to ignite the dust/air mixture

Minimum ignition temperature. The lowest temperature of heated wall that ignites the dust/air mixture upon brief contact

Lower explosive limit (LEL). A concentration of dust in air below which there is insufficient material to support the combustion at the rate required for an explosion. A typical LEL for dust is ~30 g/m^3. A dust layer on the floor with a depth of 1 mm can exceed the LEL if it becomes airborne.

K_{St} value. A classifying parameter that describes the volatility of the combustion. It is equal to the figure for the maximum speed of pressure build-up during the explosion of a dust/air mix in a container measuring 1 m^3

Additional factors. Other factors affecting dust explosions include the dust particle size, the chemical properties of the dust, the moisture content and the cloud dispersion. Although no exact parameters exist for moisture, it is known moist dust requires a higher ignition temperature and is less likely to be swirled up into the air.

TABLE 1. COMPARATIVE PARTICLE SIZES

Particle type	Particle size, μm
Period (.)	615
Beach sand	100–10,000
Mist	70–350
Fertilizer	10–1,000
Milled flour	1–100
Grain dusts	5–1,000
Pollens	10–1,000
Human hair	40–300
Saw dust	30–600
Ground limestone	10–1,000
Cement dust	3–100
Mold spores	10–30
Textile dust	6–20
Fly ash	1–1,000
Coal dust	1–100
Iron dust	4–20
Smoke from synthetic materials	1–50
Paint pigments	0.1–5
Carbon black dust	0.2–10
Atmospheric dust	0.001–40
Smoke from natural materials	0.01 – 0.1
Coal fluegas	0.08–0.2
CO_2 molecule	0.00065

Source: EngineeringToolbox.com

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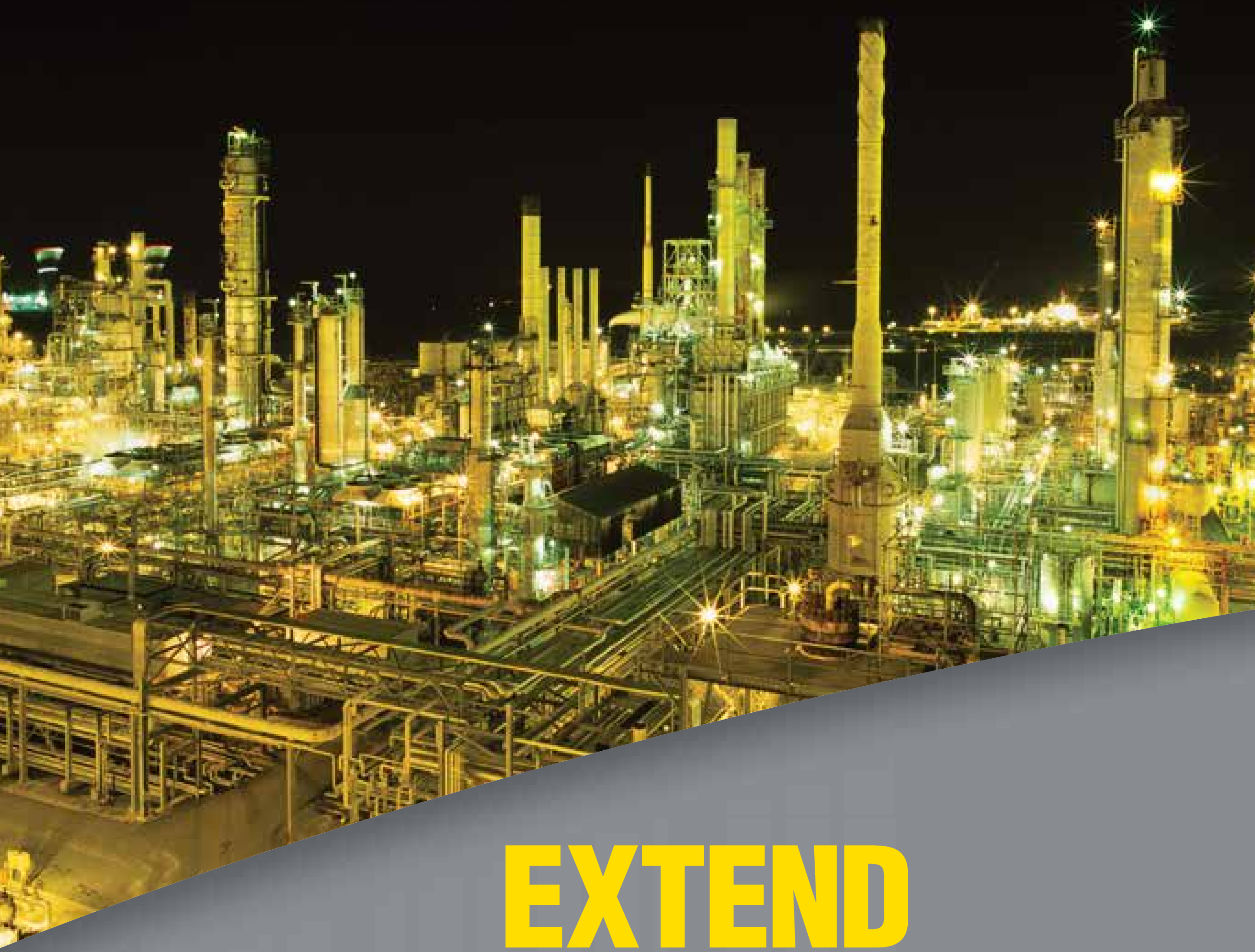

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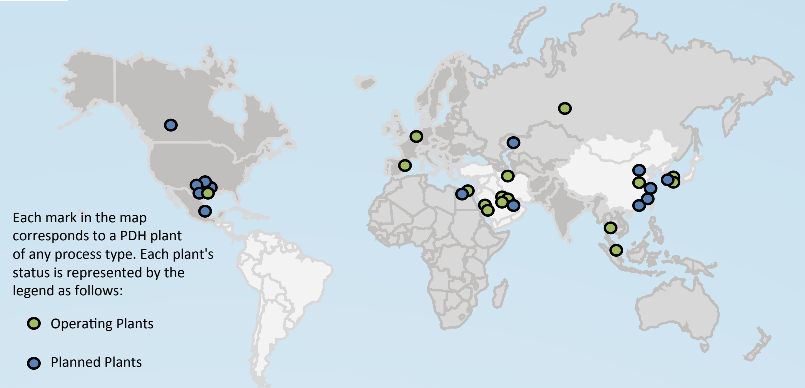
Technology **Profile**

Propylene Production via Propane Dehydrogenation

By Intratec Solutions

Propylene is the second most important intermediate in the petrochemical industry after ethylene, and its global demand is dominated by the production of polypropylene. However, the growing use of natural gas from shale deposits as a raw material for steam crackers and fluid-catalytic-cracking (FCC) units in the U.S. is slowing propylene production, because it is mainly obtained as a byproduct of naphtha-cracking processes. The same shale gas is also responsible for the increasing amount of propane and ethane available in the market.

In this scenario, routes to obtain propylene from lighter feedstock, instead of from crude oil, are becoming more and more interesting. Thus the propane dehydrogenation (PDH) reaction is a promising alternative to meet the rising global propylene demand (see Newsfront, pp. 13–16). One approach to PDH is a process developed by UOP LLC (Des Plaines, Ill.; www.uop.com) that was covered in this column last year (*Chem. Eng.*, February 2013, p. 33). A second approach, developed by Lummus Technology, now part of CB&I (The Woodlands, Tex.; www.cbi.com), is discussed here.



Each mark in the map corresponds to a PDH plant of any process type. Each plant's status is represented by the legend as follows:

● Operating Plants

● Planned Plants

FIGURE 2. Existing and planned propane dehydrogenation plants globally

The process

PDH reaction is an endothermic catalytic process that converts propane into propylene and hydrogen. Figure 1 illustrates a technology similar to the Catofin process, by Lummus Technology, which uses fixed-bed reactors and a chromium-based catalyst. It is carried out in two main areas: reaction and regeneration; and product recovery. The yield of propylene is about 85 wt.%. The reaction byproducts (mainly hydrogen) are usually used as fuel for the reaction. As a result, propylene tends to be the only product, unless local demand exists for the hydrogen byproduct.

Reaction and regeneration section. Fresh propane feed is mixed with recycled propane from a propylene-propane splitter. This stream goes to a de-oiler for impurities removal and then is carried to the reaction step, which is continuous and operates in cycles. In this step, multiple reactors undergo a controlled sequence of reaction, catalyst reduction and catalyst regeneration.

Product recovery section. In this area, there is a low-temperature separation unit, the objective of which is to separate hydrogen and light byproducts generated in the reaction step from the main product. The hydrogen-rich stream is then sent to a pressure-swing adsorption (PSA) unit. The liquid stream generated in the low-temperature separation is fed to distillation facilities for product recovery. The distillation facilities consist of a de-ethanizer and a propylene-propane splitter, the latter producing the recycled propane stream that is used in the reaction step.

Economic performance

An economic evaluation of this PDH process was conducted for two distinct locations — the U.S. Gulf Coast and China — and is based on data from the first quarter of 2013. The following assumptions are made for the analysis:

- A 590 ton/yr capacity unit erected in a petrochemical complex
- No storage of feedstock or product is considered

The estimated capital investment (accounting for the total fixed investments, total working capital and other capital expenses) for such a plant in the U.S. Gulf Coast is about $500 million, while in China, it is $420 million. For operational expenditures, the situation is reversed. A facility in the U.S. Gulf Coast region would have the lower operating expenses: $750/ton, while those for a facility in China would be $1,300/ton.

Global perspective

According to estimates, PDH processes will account for most of the global on-purpose propylene production. The regions leading this global change are mainly the U.S. and the Middle East, because of low costs for propane (Figure 2). China can also be considered a hotspot, since the country is home to several projects involving PDH plants. The growing access to low-cost propylene experienced by these countries will make their national plastic industries more competitive when compared to South American or European plastic makers. ■

Edited by Scott Jenkins

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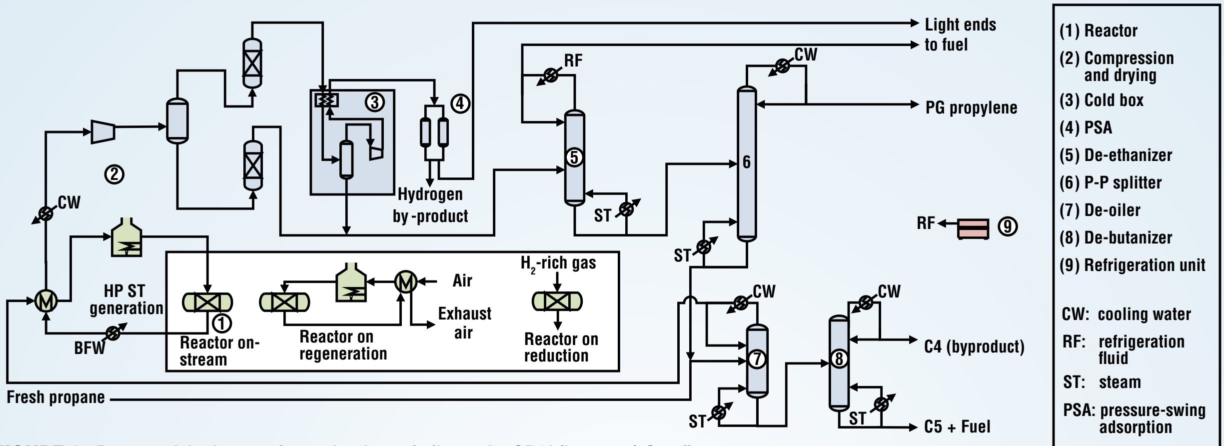

FIGURE 1. Propane dehydrogenation technology similar to the CB&I (Lummus) Catofin process

Pressure-Vessel Quality Control Requirements

Understanding what is required for boiler and pressure-vessel manufacturers can help scheduling and cost assessments

Keith Kachelhofer
Hargrove Engineers + Constructors

Pressure vessels are common in the chemical process industries (CPI) and they range widely in size and complexity. Process engineers may be tasked with inspecting a new pressure vessel or with witnessing hydrostatic testing of a vessel. In addition, engineers could be asked to witness repairs or alterations to a pressure vessel already in service, during day-to-day process and maintenance operations. Included within these tasks is the requirement to develop a maintenance, repair or alteration schedule for the pressure vessel job and to determine the associated cost.

Establishing a clear understanding for process engineers of the requirements placed on pressure vessel manufacturers by the ASME (American Society of Mechanical Engineers; New York; www.asme.org) Boiler & Pressure Vessel Code (ASME BPV, or the Code) and the National Board of Boiler and Pressure Vessel Inspectors (NB; Columbus, Ohio; www.nationalboard.org) will avoid confusion and enable an accurate assessment regarding schedule and economic costs. This article is intended to explain the fundamental requirements of pressure vessel construction to which vessel manufacturers, or qualified certificate holders, must adhere. This includes requirements within their own organizations, as well as those stipulated by ASME and the National Board.

The requirements are outlined in the vessel manufacturer's quality control manual, a document that manufacturers must develop and publish for review by the National Board and by authorities in their local jurisdiction.

FIGURE 1. Vessel manufacturers need to have a system for identifying nonconformities, such as this scratch in a vessel component

Historical origins

The foundation of the boiler and pressure vessel code lies with ASME. The development of the Code was in response to a boiler explosion at the R.B. Grover Co. in Brockton, Mass. in 1905. In 1907, the State of Massachusetts enacted the first legal code of rules for the construction of steam boilers. The State of Ohio would follow with similar legislation in 1908. In 1915, the ASME released its first draft of the 1914 edition of ASME Rules for Construction of Stationary Boilers and for Allowable Working Pressure. From 1907 to 1915, other states formulated rules for the design, construction and inspection of steam boilers and pressure vessels. However, the rules varied from state to state, resulting in increased engineering and construction costs.

In response to the varied rules, the National Board of Boiler & Pressure Vessel Inspectors was formed. The NB is a nonprofit organization consisting of members from each local jurisdiction that has adopted the ASME BPV code. Jurisdictions could be states, commonwealths, counties or municipalities of the U.S. or Canada.

QUALITY CONTROL

A manufacturer who wants to fabricate pressure vessels in accordance with the ASME BPV must obtain a contract with an authorized insurance agency and develop a written quality control (QC) program for its manufacturing operation. An authorized insurance agency (AIA) is one that has been licensed or registered by the appropriate authority of a state to write boiler and pressure vessel insurance and that can provide all inspection services required by each local jurisdiction. The AIA works with the manufacturer to develop a quality control program that meets the requirements of the ASME BPV code.

Appendix 10 of the BPV Code is a mandatory appendix that outlines the content that pressure vessel manufacturers must include in the quality control manual.

An authorized inspector (AI) is an NB-commissioned inspector who has met the educational and experience requirements of the National Board, successfully completed the NB Commission Examination, and who has agreed to comply with the requirements of the jurisdiction wherein the inspector is performing inspec-

FIGURE 2. Welders must be qualified for each procedure listed in the vessel fabrication drawings

tions. The AI must be employed as a boiler inspector by a jurisdiction, an AIA, or an owner-user inspection organization. Requirements regarding education and experience that an individual must have to become a commissioned inspector can be found on the NB website.

Using the rules and philosophy of the Code, the manufacturer and the AIA ensure the vessel is designed and fabricated with quality and safety for the general public.

QC manual requirements

The Code clearly defines the quality control (QC) program as a system that suits the circumstances of the manufacturer. Since each manufacturer has projects varying in size and complexity, their quality control program should reflect such efforts. The Code does not define the length or complexity of the manufacturer's quality control manual. The description of the manufacturer's program can be "brief or voluminous."

Provided here are the requirements used to describe the manufacturer's quality control system.

Statement of authority and responsibility. This statement authorizes the manufacturer's quality control manager to identify quality problems and to initiate and implement solutions. The quality control manager should have well-defined responsibilities, along with the authority and organizational freedom to carry them out. This statement must bear the proper signatures.

Organization. The manufacturer must provide an organizational chart that provides titles showing the relationship between the management team and the quality control, purchasing, engineering, fabrication, testing and inspection departments. The Code does not intend to encroach on the manufacturer's right to alter its organizational scheme.

Drawings, design calculations and specification control. The manufacturer must provide the procedures that will ensure that the latest applicable drawings are being used in the shop and that the design calculations and material specifications are in accordance with the latest edition and addenda of the Code. The manual must ensure that drawings and calculations are reviewed for accuracy and for compliance with the Code. The person responsible for this within the manufacturer's organization will also have to review these documents with the AI, who will assign desired inspection points throughout the fabrication process.

The manufacturer may accept calculations prepared from others, provided that these provisions are outlined in the quality control manual. For example, the quality control manual can have a provision for accepting calculations from another entity, but may require the calculations be sealed by a registered professional engineer who is experienced with the boiler and pressure vessel code. It is the manufacturer's responsibility to ensure that the calculations meet the requirements of the Code. There should be a provision in the manual for control of fabrication drawings on the shop floor. The manufacturer needs to ensure that a procedure exists for collecting old revisions of shop drawings and distributing new revised shop drawings.

The method of handling design changes for calculations and specifications, such that the AI can review and verify these changes, must be stated in the manual.

Material control. The manufacturer must have a system implemented to ensure that only acceptable materials are being utilized in the fabrication of a vessel. The quality program shall have a receiving process to verify that the material received meets the specifications of what was ordered and meets the requirements of the Code.

Examination and inspection

This section is the core of the quality control program, outlined by the manufacturer. In this section, the manufacturer should describe all functions of examinations, tests and inspections from the time the material is delivered to the shop until the vessel is certified and shipped to the customer. The following represents the elements of this section.

Correction of nonconformities. Nonconformities are inherent in any vessel fabrication process (Figure 1). Two types of nonconformities are commonplace: those found during fabrication and those found in material. A nonconformity is defined by the Code as any condition that does not meet the applicable rules of the particular division under which the vessel is manufactured. The vessel manufacturer shall have a system in place to identify and correct nonconformities. The manufacturer will use hold tags to identify nonconforming materials and a nonconformance report, which must be filed until the matter can be taken into disposition with the authorized inspector.

Welding. All welders used in the fabrication of pressure vessels must be qualified in accordance with the ASME BPV Code, Section IX. The manufacturer needs to have a written procedure for qualifying and testing welders and welding procedures and a written procedure for the purchase, receiving and storage of all welding consumables should be included (Figure 2).

Nondestructive examination (NDE). Boiler and pressure-vessel manufacturers are required to have in place a written procedure for assuring all nondestructive-examination personnel are qualified in accordance with the Code. Manufacturers must distinguish those NDE procedures that will be performed in the shop from those NDE procedures that will be performed by a qualified third-party facility. When a third-party facility is subcontracted, the manual must designate who within the manufacturer's organization will verify whether the subcontractor meets the qualifications and requirements of the Code. For nondestructive examination processes within the manufacturer's organization, the manufacturer must provide sufficient evidence that all nondestructive examination personnel and procedures meet the requirements of the Code.

Heat treatment. Due to certain design conditions and materials of construction, heat treatment may be required. Since most manufacturers do not have heat treatment capabilities, the process may be subcontracted. As a result, the manufacturer will need to provide an explanation of the methods used for heating, cooling, metal temperature measurement and temperature control.

Calibration of measurement and test equipment. Manufacturers need to have implemented a process for documenting the frequency and identification of all calibrated measurement and test equipment. The quality control manual should provide an explanation of the use of the hydrostatic test gage and the hydrostatic master gage.

Records retention. The ASME Code requires the manufacturer to maintain records for a minimum of three years for vessels fabricated under Div. I and II. This includes: manufacturer's partial data reports; manufacturing drawings, design calculations; material test reports and material certifications; welding procedure specifications (WPS) and procedure qualification records (PQR); welders qualification records; ultrasonic testing (UT) and radiographic testing (RT) reports; repair procedures and records; process control sheets; heat treatment records and test results; postweld heat treatment records, nonconformances and dispositions and hydrostatic test records.

Sample forms. These are the forms used by the manufacturer in the fabrication of the vessel. They typically include welder's log records, traveler sheets, non-conformance tags and so on. Sample forms should be displayed in an appendix in the quality control manual, along with an explanation of their use. These forms ensure the AI that the manufacturer is organized and has established good procedures.

Inspection of vessels and parts. Inspection of the vessel and its associated parts must be performed by the inspector throughout the fabrication process. The quality control program shall make the manufacturer's fabrication facilities and a copy of its quality control manual available to the AI. The manufacturer's quality control manual should clarify that all drawings, calculations, process sheets, check lists and any other quality control records shall be made available for the AI's review.

Upon receipt of a purchase order to construct a vessel, the manufacturer will assemble a file or project notebook that tracks, in sequence, each stage of the manufacturer's design and fabrication process. The file should include a traveler, calculations, a weld map, material test reports (MTRs), receiving reports, NDE reports, non-conformance reports and vessel fit-up (initial assembly of vessel components with tack welds) inspections for shells, heads and nozzles.

The traveler essentially provides a checklist of the items inspected and reviewed by the AI and the quality control manager during the fabrication process. A traveler ensures the AI that the manufacturer is in compliance with his or her own quality control program. The quality control manager must initial and date each task as it is inspected throughout the entire process. Before the fabrication process begins, the AI must perform an initial review of the vessel design to ascertain the complexity of the fabrication and determine where "hold" points are to be assigned. Hold points are essentially items that the AI wants to inspect prior to the commencement of fabrication or the completion of the vessel and hydrostatic test.


FIGURE 3. A closure-head assembly could be designated as a hold point

Typically, hold points are automatically assigned to items such as calculations, drawings, RT film review, data reports and application of the nameplate and Code stamp. For smaller vessels with small inspection nozzles, it is not uncommon for the AI to place a hold point on the closure head of the vessel (Figure 3). This gives the inspector the ability to inspect the inside of the vessel while it is more accessible.

If the AI has assigned hold points to items such as vessel fit-ups or inspection of root welds, then he or she can elect to waive the hold point verbally. This verbal waiver should be documented on the traveler. If the AI has concerns with the manufacturer's ability to satisfactorily follow its own quality control program, the AI can have the manufacturer stop production on that vessel until it can be inspected. The AI cannot waive hydrostatic testing,

FIGURE 4. Materials to be used for fabricating pressure vessels are inspected to verify compliance with the ASME Boiler and Pressure Vessel Code

FIGURE 5. Material markings must match the information in the material test report (MTR)

application of the data plate, application of the Code stamp or the manufacturer's data report.

INSPECTOR REVIEW

The vessel calculations and drawings are the first items to be reviewed by the AI. The manufacturer's engineering department will perform the calculations and create the drawings. It is the quality control manager's responsibility to interact with the engineering department to confirm that the design meets the requirements of the Code and to check the calculations for accuracy. Depending on what is suitable to the manufacturer, the AI will request a review of the calculations and drawings prior to procurement of material. During this review, the AI is looking to see if the calculations are performed in accordance with the philosophy of the Code.

The AI is not responsible for checking the calculations for correctness or accuracy. This is a common misconception among engineers in the CPI. Section UG-90(b) of the Code states that the AI is to verify that the applicable design calculations are available. It is the responsibility of the manufacturer and the AI to agree on the method used to generate calculations.

Another misconception has to do with the validation of computer software. Per Code Interpretation VIII-1-86-64, computer-generated calculations from specialized computer software do not require documentation to validate their accuracy. Validation of the computer software is preferred, but is not a requirement. However, some authorized insurance agencies will require validation of the software.

During the drawing review, the AI is looking for the following: basic dimensional information on the vessel; material of construction; operating temperature; maximum allowable working pressure (MAWP); degree of radiography; corrosion allowance; and a nozzle schedule. The drawing should also provide the edition of the ASME code and addenda by which the vessel is being constructed. Most data provided on equipment specifications when the project was quoted should be found on the drawing.

One additional aspect is a list of the manufacturer's qualified weld procedures to be used. The weld procedures can be identified in numerous ways, such as in table format or identified with American Welding Society (AWS) standard weld symbols. During the review, the AI may check to see if the weld procedures listed on the drawing have been qualified by the manufacturer, and if they meet the requirements for fabricating the vessel as outlined in UW-47 of the Code. The nozzle schedule should provide nominal size, schedule thickness, flange rating, material of construction and the intended service. Some AIAs prefer to see at least one nozzle identified for overpressure protection included in the nozzle schedule.

Vessel requirements

Vessels subject to internal corrosion, erosion or mechanical abrasion are required to have inspection opening(s) per UG-46 of the Code. If the vessel is less than 18-in. I.D. and over 12-in. I.D., then the vessel must have at least two handholes, or two plugged and threaded inspection openings no smaller than 1.5 in. NPS. If the vessel is 18–36 in. I.D., then there should be either a manway, two handholes or two plugged, threaded inspection openings not less than 2 in. NPS (nominal pipe size). For vessels in excess of 36-in. I.D., there must be one manway opening, with the exception that two 4 × 6-in. handholes can be used if the vessel geometry does not permit a manway.

Nozzles attached to piping or instrumentation can be used for inspection openings as long as the openings meet the requirements for size and the nozzles are located to afford an equal view of the interior of the vessel. It is the user's responsibility to identify the inspection openings on the vessel prior to design and fabrication.

All vessels are required to have overpressure protection in accordance with UG-125 of the Code. The relief device can be located directly on the vessel or installed within a process or utility pipeline connected to the vessel. On either account, the AIA may require identification of the nozzle that will be connected to the safety-relief device. The identification of the nozzle for safety relief is the responsibility of the user, and should be discussed internally in the context of the user's process-safety review.

Material requirements

Materials of construction for the vessel delivered to the manufacturer must be inspected to verify compliance with the Code. For plates, the manufacturer shall verify that the slab number, heat number and material grade marked on the plate match what is shown on the material test report (MTR) provided by the supplier (Figures 4 and 5). The plate must be verified for dimensional size and nominal thickness. Since plates are sold by weight, the thickness can be larger than what is specified. In addition, the manufacturer will examine the plate for signs of de-lamination, deep gouges or other defects.

If the product form is pipe, the manufacturer will examine the material for the length, nominal diameter and nominal thickness. It is important to remember that the pipe wall thickness is allowed an undertolerance of 12.5% (per Section UG-16(d) and UG-45(b)(4) footnote 26). Like the plate, the manufacturer shall verify that the heat number and material grade marked on the pipe match what is provided on the MTR. During the receiving and inspection process, some manufacturers will transfer the job number, heat number and material grade to three or more locations on the pipe and plate with the intention of helping the shop transfer these numbers once material starts to be formed, cut and removed (Figure 6).

Transferring these numbers is to ensure the manufacturer is in accordance with UG-77 of the Code, which requires traceability on all material to the original identifying markings. For carbon steel, the markings are made with a white or yellow paint marker. For stainless steel, markings are typically made with a black permanent marker. For manufactured components purchased from another manufacturer, (that is, vessel heads), the vessel manufacturer must dimensionally check vessel heads to the prescribed dimensional tolerances and verify that the head meets the minimal thickness required by the calculations, as outlined per UG-96 of the Code. Most manufacturers will not begin rolling shell plate for vessels that incorporate cold-formed heads until the heads have arrived at the manufacturer's facility and the dimensions are confirmed.

Per UG-81 of the Code, the heads cannot deviate in nominal outside dimensions by more than 1.25%, and no more than 0.625% for inside dimensions. The nominal diameter of the head will govern the final dimensions when the shell plates are rolled. Accurately made templates are to be made for verification of the head geometry.

FIGURE 6. Pressure vessel manufacturers transfer information to three or more locations on the piece

It is important for the user to understand that the thickness verification of a torispherical or ellipsoidal head should be performed at the knuckle regions, and the top-center of the head where the product will thin the most during cold-forming.

Most shops own an ultrasonic testing (UT) instrument used to measure alloy thicknesses. Gage thickness testing on the straight flange of a vessel head is not preferred. Parts manufactured at a location other than the manufacturer of the vessel, such as elliptical handholes or T-bolt closures, shall be provided with a Manufacturer's Partial Data Report Form U-2 or U-2A. The parts manufacturer and its affiliated AI will validate that the part is in accordance with the Code. For manufactured Code parts, some manufacturers will write the job number and material grade on the part to minimize error. For flanges, the product will have the material grade and compliance with ASME B16.1 stamped on the outer edge of the flange.

The manufacturer will inspect the flanges for defects, such as scratches or damage to serrated raised faces. All plate and pipe form, along with flanges and fittings, should be located in a designated area separate from non-Code materials. The details of how this material is stored, identified and inspected, along with the generation of the receiving reports, are outlined in the manufacturer's quality control manual.

As material is received, the quality control manager is responsible for verifying that the supplier's MTR is in accordance with the Code. The MTR will be checked for proper identification of material with the proper Code specification of ferrous or nonferrous metal, and so on. For example, stainless plate is designated by ASTM International (www.astm.org) as A240-316L, whereas the Code will require the designation of SA240-316L. When referencing the ASME BPV Code, Section II, Parts A and B, the materials accepted by the Code will be identified as equivalent to the ASTM standard where applicable. Therefore, when reviewing the manufacturer's shop drawings, the user should note that all material specified on the drawing bears the ASME designation and not the designations of ASTM.

The quality control manager will crosscheck the percentage of constituents in each alloy on the MTR with those provided by ASME, Section II, Parts A and B. If the material for use with the vessel is within the allowable limits of the Code, the MTR will be filed and the traveler will be initialed and dated by the quality control manager. For some manufacturers, the MTRs are initialed and dated by the quality control manager the day they are reviewed and the material is received. The Code does not specify at what point the material test reports must be verified with the requirements of Section II. This is clarified in the Code interpretation VIII-1-86-129.

If the material supplied is found to have defects, or an MTR indicates its chemical composition does not meet the requirements of the Code, the manufacturer will generate a non-conformance report and place a non-conformance "hold" tag on the material in question. The manufacturer's quality control manual will list the procedures to be carried out and the persons within the organization who are involved with

FIGURE 7. Radiographs can reveal flaws not visible in outer appearance

the non-conformance. The AI will review the report and the corrective action(s) taken and will then sign and date the report and traveler, signifying that he or she has been made aware of the non-conformance.

Fabrication

During fabrication, the manufacturer should perform proper vessel fit-up inspections. This process is to confirm the proper edge preparation, proper alignment of longitudinal and circumferential shell plate seams, proper location of nozzles, proper fit-up of nozzles, proper location of lifting lugs, support attachments and miscellaneous appurtances. The AI will determine if there is a need to inspect the fit-up on a vessel, and it is the manufacturer's responsibility to make fit-up inspections available.

During the welding and fit-up inspection, the manufacturer's quality control system will document which welder completed the fabrication of each nozzle and completed weld seams for each longitudinal and circumferential joint on the vessel. This includes the welding of support steel, lifting lugs and attachment lugs.

Section UW-37(f) of the Code requires each welder to identify the seams that they have welded with the letter, number or symbol that has been assigned to them by the manufacturer. The Code requires the manufacturer to assign a letter, number or symbol to each welder, as outlined in UW-29(c). In addition, the quality control manager will mark each component and weld seam on a weld map of the vessel, indicating each welder who performed each operation and the date on which it was completed.

All tack welds used during the fit-up of a vessel shall be made by qualified welders using the manufacturer's qualified welding procedures. The quality control manual should address whether or not the tack welds will be incorporated into the weld of the vessel or if they will be ground out once the root pass has been started.

In addition, the quality program verifies that all material grades and heat numbers have been transferred from the stock material to each individual pressure-retaining component. This includes all pipe and tube material, as clarified in Code interpretation VIII-1-98-44. The Code does not require the transfer of material markings to non-pressure-retaining parts, such as lift lugs, legs, support skirts and so on, per Code interpretation VIII-1-92-89. However, it is not uncommon for most shops to transfer marking to non-pressure-retaining items in order to maintain consistency on the shop floor. The quality control manager will coordinate with the shop foreman to determine which welders will be assigned to the vessel during fabrication.

Welding requirements

The quality control manager is responsible for verifying that each welder is qualified for the procedures listed on the fabrication drawings, and that each welder has performed these operations within six months prior to welding on the vessel. If the welder has not met the six-month requirement, or if the parameters of a qualified weld procedure have changed, then his or her qualifications have expired and he or she must be tested and requalified, as outlined in Section IX, QW-322 of the Code. The manufacturer's quality control manual will outline the procedure for certifying a welder's qualification. It is important to understand that the Code does not certify welders, or guarantee that the welders meet the standard. Only the manufacturer can qualify a welder as being competent in meeting the requirements of the weld procedure developed within the manufacturer's organization.

The quality control manual must outline the handling of all welding consumables. All filler metals should be stored in a dry area and signed out through a designated person(s). Low-hydrogen coated electrodes should be stored in "hot boxes" or rod ovens and quantities issued to the welder(s) should be sufficient to complete a weld or for the duration of a shift, whichever is less. The low-hydrogen coated electrodes will absorb moisture, and over time, the moisture will affect the quality of the electrode.

Throughout fabrication, the manufacturer's quality control manager will perform a visual inspection of the welds to ensure they meet the requirements of the Code and good manufacturing practices. Welding undercut, gouges in the base metal or other quality-related issues must be documented as nonconformance items and resolved within the manufacturer's organization.

Non-destructive examination

The basis of design will determine the level of non-destructive examination (NDE) required. Although the outer appearance of a weld might look acceptable, the weld could contain excessive porosity, lack of fusion, undercutting or cracks (Figure 7). The quality control manager will review the NDE reports and verify that they meet the needs of Section V of the Code. When reviewing NDE reports, the quality control manager will confirm that the NDE personnel are qualified in accordance with SNT-TC-1A (guidelines from the American Society for Nondestructive Testing for employer-based certification of testing personnel). Once the NDE is completed and the reports submitted, the quality control manager will initial and date the traveler.

Most manufacturers perform their own NDE inspections, such as dye-penetrant examination (Figure 8). However, the manufacturer must meet the requirements of Section V, which include a written procedure on how the NDE will be performed, a test plate to qualify shop personnel, and a record of the yearly eye exams for qualified persons.

With regard to interpreting radiography, the manufacturer shall have a qualified NDE contractor with personnel who meet the requirements of SNT-TC-1A. An AI may be fully qualified in accordance with SNT-TC-1A but cannot be the only qualified individual to interpret the radiographs as outlined in interpretation VIII-1-86-19. However, an AI does have the authority to reject radiographs, for legitimate reasons, that have been interpreted and accepted by a Level II or Level III radiographer. As stated in interpretation VIII-1-86-42, the AI is not required to review all radiographs, but must review a sufficient number of radiographs to verify the examination was performed and the results were acceptable per the Code. The Code does not require a specific percentage of radiographs required to be reviewed by the AI.

Report forms

Near the completion of the vessel, the manufacturer will generate a Manufacturer's Data Report Form U-1 or Form U-1A. Any effort to complete necessary paperwork before the final inspection and hydrostatic test will help reduce the time and cost associated with the AI.

The manufacturer's quality control system should provide procedures explaining the development, control, retention and distribution of the data reports. Form U-1 is a two-page report allowing data entry for more sophisticated vessels, such as heat exchangers with multiple chambers, tubesheets and tube sections. Form U-1A is an alternative one-page report for single-chamber vessels fabricated entirely in a shop or in the field. The manufacturer can increase the number of lines on the data report to describe additional shell courses or nozzles.

The format of the data report as shown in Appendix W of the Code is nonmandatory and can be altered in appearance. However, the data report must address all information on the sample data report provided in Appendix W. If the data report exceeds one page, there must be sufficient space on each additional page for the manufacturer and the AI to initial and date it.

If the manufacturer needs additional room to provide detailed information for the vessel or its components, Form U-4 can be submitted with Form U-1/ U-1A. Form U-4 is the manufacturer's supplementary data sheet that provides additional space for remarks. Reduced sketches and drawings can be added. If the user desires to have a small image showing the configuration of the vessel, it can be added to Form U-4 and filed with Form U-1 / U-1A. If the vessel is registered with the National Board, the manufacturer's data reports are the only items filed. Shop drawings are not included with the registration. It is the responsibility of the user to request reduced sketches and vessel configuration drawings added to Form U-4 when the purchase order is generated. Manufacturers of vessels will not go to extended lengths to provide more information than what is required by the Code.

During final inspection, the AI should review the shop drawings to check for revisions made since the initial review and make a last review of the calculations, if necessary.

The traveler will also be reviewed. There should be a chronological order of inspections that have taken place since the inception of the package included on the traveler. The AI will review the material test reports (MTRs) and the material inspection reports for the construction material used on the vessel. The AI will also confirm that the MTRs were reviewed by the manufacturer's quality control program, and that the material was delivered in acceptable condition. Next, the weld map will be reviewed to verify that there were inspections for fit-up and the manufacturer's welders were identified for each component on the vessel.

Depending on the AI's level of confidence with the manufacturer, he or she may select a welder from the weld map and request to see the welder's performance qualification record (WPQ) and the procedure qualification record (PQR) for the welding operation performed. NDE reports will be provided with the package if the design requires examination. The AI will review the reports to confirm compliance with the Code.

FIGURE 8. The dye penetrant test, an example of NDE, can reveal weld leaks

During this review process, the AI will initial and date the traveler as he or she reviews the inspection items not witnessed during fabrication. All inspection items on the traveler should have already been inspected, initialed and dated by the manufacturer's QC manager during the vessel fabrication process.

Within the final review of the package, the AI will perform a final inspection of the vessel. This consists of a visual inspection of the vessel prior to sandblasting, painting or passivation. This inspection is to ensure the material grade and heat numbers have been transferred from the stock material to each pressure-retaining component. Welds are inspected externally for indications of excessive reinforcement, signs of improper start-stops or undercut. Fillet welds may be inspected for proper size on nozzles and lug attachments. The detailed placement of nozzles on the vessel head and shell are not the responsibility of the AI; they are the responsibility of the manufacturer as part of good manufacturing practices.

POST-FABRICATION

A standard hydrostatic test, for ensuring the strength of the vessel and checking for leaks, can only be conducted once the fabrication of the pressure vessel has been completed and all NDE performed. Some operations, such as cosmetic grinding to remove weld spatter, are permitted after the test. The hydrostatic test shall be in accordance with UG-99 of the Code, where every pressure-retaining item in the vessel will be subjected to at least 1.3 times the maximum-allowable working pressure marked on the vessel nameplate. The Code further clarifies that the lowest ratio of the stress value at test temperature to the stress value at design temperature shall be multiplied by 1.3 and the maximum-allowable working pressure.

During the hydrostatic test, the AI will perform a visual examination of the vessel, looking for leaks and a drop in pressure. Test times can be 15 min or longer, depending on the size and complexity of the vessel. Test gages will consist of an indicating gage connected directly to the vessel, along with a master gage. Per Code interpretation VIII-1-89-207R, the indicating gage does not have to be mounted directly on the vessel, but should be directly connected to the vessel with no intermediate valves.

In addition, the gage is not required to be connected at the highest point on the vessel. Both gages should range greater than 1.5 times, but not more than 4 times the hydrostatic pressure. Both gages should provide the same reading and be calibrated against a deadweight tester or master gage. The manufacturer's quality control manual should provide a detailed explanation of how often these gages are calibrated and how the calibration records are filed. Only after the hydrostatic test has been performed can the vessel nameplate be stamped and attached to the vessel.

Vessel nameplates

Vessel nameplates are typically attached to a bracket that protrudes at least 4–6 in. off the vessel wall to prevent cover up by insulation. The preferred practice is to install the nameplate over an inspection nozzle or manway, as recommended in UG-116(i) of the Code. The AI must witness the stamping of the nameplate and the attachment of the nameplate to the vessel. Once the attachment of the nameplate has been witnessed, the AI and the quality control manager will initial and date the traveler, indicating that the vessel is complete.

Upon application of the vessel nameplate, the AI and quality control manager will review the Manufacturer's Data Report Form U-1/U-1A for validity, omissions and errors. Once the data report is complete, the AI will provide his National Board Commission number, and will sign and date the document. The quality control manager will also sign and date the document and start the filing process. The Code does not address the timeframe in which the manufacturer's data report must be signed. It is the responsibility of the manufacturer to apply the nameplate and see that the manufacturer's data report is signed by the AI.

The manufacturer is required to furnish a copy of the manufacturer's data report to the user and submit a copy to the local jurisdiction where the vessel is installed and the Code enforced. The manufacturer is required to keep a copy of the manufacturer's data report on file for a minimum of five years if the manufacturer does not file the vessel with the National Board of Boiler & Pressure Vessel Inspectors, as mandated in UG-120(4).

It is suggested that the user require the vessel to be registered with the National Board of Boiler & Pressure Vessel Inspectors.

Repairs and alterations

For repairs and alterations of pressure vessels, the manufacturer is still required to maintain the quality control plan outlined within the organization. However, the manufacturer must have a National Board "R" Certificate of Authorization, since the manufacturer's "U" Certificate of Authorization for new construction does not permit repairs and alterations. The requirements for repairs and alterations are outlined in the National Board Inspection Code (NBIC).

For repairs and alterations, the manufacturer shall determine the construction standard by which the vessel was originally fabricated. This could be an earlier edition and addenda to Section VIII, Division I, or the vessel could have been fabricated under another division of the Code. Second, the manufacturer shall determine the material of construction of the vessel. The material of construction will determine which qualified weld procedures and qualified welders can be used on the project, and the level of NDE. Also, the material will determine if post-weld heat treatment or stress relieving is required. Third, the manufacturer needs supporting documentation which provides evidence that the vessel under repair or alteration was indeed fabricated in accordance with the original Code. The ideal situation is to obtain a rubbing of the vessel nameplate and confirm that it matches the original manufacturer's data report U-1 or U-1A.

The manufacturer's data report will provide the design conditions, material of construction, nominal plate and pipe thickness, and degree of NDE. If the nameplate is legible on the vessel, but the manufacturer's data report is not on file with the owner, then a copy of the manufacturer's data report can be obtained through the National Board. The NB will require the following information from the vessel nameplate: the manufacturer's name, NB number, serial number and date of manufacture. Data reports can be sent electronically, or via postal service or courier. ■

Edited by Scott Jenkins

Author

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Seven Tools for Project Success

Having the right tools is essential for success. These tools are of use to both novice and experienced project managers

Jeffrey S. Harding
CH2M Hill

Have you ever heard someone say, "The job is a lot easier if you have the right tools?" Having the right tools is critical to the success of craftsmen, such as carpenters, electricians, plumbers and the like. The same holds true for managing projects. Initiating a project raises many questions (such as: What will we do? How will we do it? Who will do it? How much will it cost? When will we do it?). Using the right tools can help you arrive at answers to these questions and be successful on your projects.

While this article is directed to the novice or part-time project engineer or project manager who is involved in small capital projects at the plant level, many of the concepts are equally applicable to all levels of expertise. If you work for a larger company, you may have some of these tools available to you in the form of project procedures, templates, checklists and so on. If not, some suggestions are provided in this article. If hiring an outside engineering firm for assistance, you want to look for a firm that has scalable work procedures and tools that can help you ensure successful project delivery.

GETTING STARTED

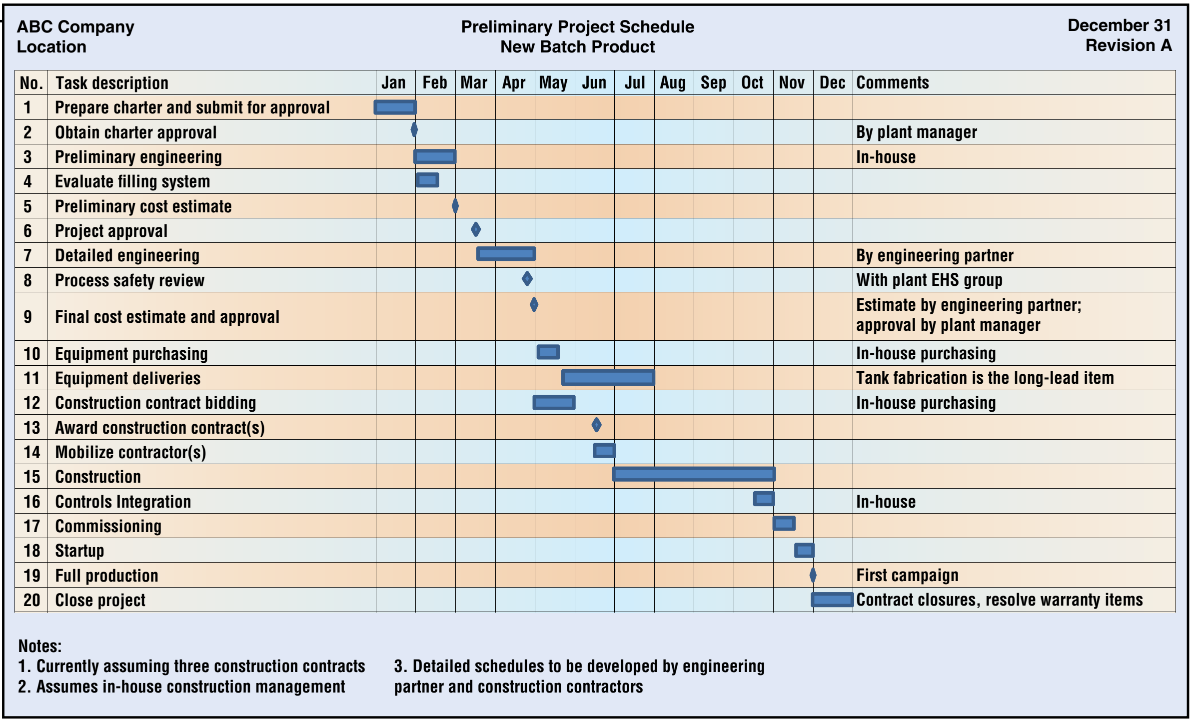
An example project

Before we get into the specific tools, let's imagine an example project. Let's say we are going to make a new product at our batch specialty-chemical plant. The research and development group (R&D) has developed the product and is piloting it. The sales and marketing team has identified a market for it and has begun selling it to customers. So now we have to start making it in larger quantities. We have existing batch-reactor capacity, but the new product involves introducing a new raw material to the site. It will be delivered in tank trucks, unloaded into a new stainless-steel storage tank, and pumped into the batch reactor through a flowmeter and control valve. (This means that additional piping, instrumentation, and controls will be required.) The product will then be pumped to a new stainless-steel storage tank using the existing reactor-outlet pump, and then pumped to a filling line for totes and 55-gal drums, which will be shipped to customers. It is not known if the existing tote/drum filling line at the plant has spare capacity. So this is our starting point.

The tools as related to FEL or FEED. One more point to make before we get into the tools is the following. Typically companies use a process to develop and define (in detail) the scope of a project. This process is often called front end loading, or the FEL process. Some companies use the term front-end engineering design (FEED), or other terms, instead. While this is a topic for another article, in short, the FEL process is a "stage-gated" project-approval process, meaning that there are decision points along the way to determine if the project continues to look attractive, and if resources will continue to be spent pursuing it. Some projects are "no-brainers" in terms of return on investment (ROI), but often suggested projects, when looked at more closely, do not meet ROI targets and are abandoned at some point along the way. Several of the tools described in this article are documents that are typically developed in the FEL process. For this example, however, let's assume our company does not use a formal FEL process. Instead, we will just do a preliminary cost estimate to get management approval to proceed.

Project charter. While not really a tool in the same sense as the others below, I suggest every project have a charter [*1*]. A charter essentially provides management approval to work on the project. It typically states the project objective(s), and because it is done before the project is fully defined, the charter tends to be a high-level overview. If your company does not have a project charter process or format, I suggest you create a simple one. It may only be a page or two in length, and generally contains authorization signatures and answers to the following questions:

- Why are we doing the project (background)?
- What is the objective or objectives (for example, to produce the new product to the specified quality levels, and do it safely)?
- What is the expected payback?
- What are some alternatives that may be considered? For our example project, this might include considering if any existing tanks could be used, or if tanks from the used-equipment market should be considered. Also, we need to determine if the existing tote/drum filling line is adequate, if it needs to be modified, or if a new one is required, as this will affect the project budget and schedule.
- What are the next few steps (for example, a scoping study or FEL 1 as described below, or enough preliminary engineering to develop a cost estimate for management approval)?



ABC Company
Location

Preliminary Project Schedule
New Batch Product

December 31
Revision A

No.	Task description	Comments
1	Prepare charter and submit for approval	
2	Obtain charter approval	By plant manager
3	Preliminary engineering	In-house
4	Evaluate filling system	
5	Preliminary cost estimate	
6	Project approval	
7	Detailed engineering	By engineering partner
8	Process safety review	With plant EHS group
9	Final cost estimate and approval	Estimate by engineering partner; approval by plant manager
10	Equipment purchasing	In-house purchasing
11	Equipment deliveries	Tank fabrication is the long-lead item
12	Construction contract bidding	In-house purchasing
13	Award construction contract(s)	
14	Mobilize contractor(s)	
15	Construction	
16	Controls Integration	In-house
17	Commissioning	
18	Startup	
19	Full production	First campaign
20	Close project	Contract closures, resolve warranty items

Notes:
1. Currently assuming three construction contracts
2. Assumes in-house construction management
3. Detailed schedules to be developed by engineering partner and construction contractors

FIGURE 1. A Gantt chart, such as this one, is commonly used to show project schedules

The charter is often used as the document that authorizes the initiation of the project. It essentially authorizes engineering (and possibly other) resources to be spent to begin defining the project. If anyone questions why you are working on the project, you can pull out the charter and show them. So for that reason, perhaps we could consider it as tool number zero, or maybe the tool belt, because having it enables you to use the other tools.

THE SEVEN TOOLS

1. Project scope document

Every project, no matter how small, should have a written scope. The scope document outlines in detail what the project is going to provide — such as, what equipment will be installed, what facilities will be required, what interfaces are required with the existing plant, and so on — and typically describes where the equipment will be installed. So where the charter answers "why" and "what" in general, the scope answers "what" and "where" in detail. Since most process projects are multidisciplinary, I like to use the different engineering disciplines as a checklist for a scope. This checklist would include, for example, the aspects of the project related to the following:

- Process (such as equipment)
- Mechanical (such as utilities)
- Piping (including insulation and heat tracing requirements)
- Instrumentation and controls
- Electrical (including power, lighting and grounding)
- Civil engineering
- Structural engineering
- Architectural requirements

Many other items also need to be considered, including the following:

- Environmental, health and safety (EHS) requirements (such as process safety management (PSM), and if applicable, permitting, hazardous materials, control of employee exposures and so on)
- Interfaces with the existing plant
- Need for temporary facilities

Sometimes it is also beneficial to clarify, in key areas, what the project is not going to provide. One example might be "this project will not upgrade the existing control system for the reactor." References [*2*] and [*3*] contain items to consider in developing the scope for the project. Some or all of these may need to be mentioned in the project scope document.

The utility of the scope document is to define what the project is going to provide and to help protect your project from scope changes, including "scope creep." Once the scope is defined and fixed, documented in the scope document, and approved by management, it is best to try to avoid any scope changes, because scope changes will likely add cost and time to your project. (Typically a formal change procedure must be used to obtain management approval to change the project scope, as most changes affect both budget and schedule.)

Scope creep is a seemingly innocuous kind of scope change. For example, someone might suggest adding a redundant flowmeter to the batching system. While this might be a great idea and can sound rather minor depending upon when it occurs, it could have a big impact. It will certainly add cost to the project (to specify, buy and install the flowmeter). The change could also cause a schedule delay, especially for example, if the project is already in construction. The scope document can be used as a shield to ward off scope changes [*4*]. If it is not in the scope document, it is not part of the project, and you should not add it — at least not without management approval.

2. Project budget

This tool is a project budget, based on a cost estimate with a documented estimate basis. The project cost estimate answers the all-important "how much" question, and typically serves as the basis for the project budget, either directly, or with some additional adjustments. That is why having a documented basis for the cost estimate is so important. Generally during the course of project definition, cost estimates of increasing detail are developed as more engineering is done and the project is better defined [5]. For very small projects, this may not be the case, but for companies that use the FEL process, this is generally true. A typical FEL process might have an initial cost estimate at the ±50% level at FEL 1, an intermediate cost estimate at a ±30% level at FEL 2, and then most companies require a ±10% cost estimate for appropriation at FEL 3.

For our example project, since we are assuming our company does not use the FEL process and this is a relatively small project, we will assemble an initial cost estimate for planning and approval purposes and then develop a more detailed estimate later, with the assistance of an engineering firm.

Often the initial cost estimates are "factored" based on the total equipment costs. So a process flow diagram (PFD) might be developed, equipment sizes may be roughed out, and an equipment list may be developed. Then, budgetary or historical equipment prices are obtained. The total equipment costs are multiplied by a factor, generally ranging from 2.5 to 4.5, depending upon the type and complexity of the process, to get an initial estimate of the total installed cost (TIC) for the project. The factor is intended to cover everything else included in the project, such as engineering, bulk materials (concrete, steel, pipe, wire and so on), construction labor, indirect costs and more. In most cases, this type of factored estimate is not detailed enough to get a project approved for funding, but is often used to get an approval to proceed to the next step. (Note also that the smaller the project, the less likely a factored estimating approach will be effective.)

Detailed cost estimates require a good bit of engineering and design, and generally involve equipment quotes and "take-offs" of quantities of materials, such as cubic yards of concrete, tons of steel, feet of pipe of various sizes and material specifications, numbers of valves and instruments, feet of wire and conduit, and so on. Unit rates are applied to these quantities to develop the cost estimate. Estimating guides such as Means and Richardson are available, but it's best to leave detailed cost estimating to the professionals. Some larger companies and most engineering companies have internal cost-estimating groups.

If your company does not have a form or format for cost estimates, it is a good idea to be sure to clearly document the estimate and the estimate basis. A spreadsheet is good for developing the cost estimate, because it can help with the calculations. Typically, the cost estimate is broken down by materials, labor and subcontracts in each of the various construction crafts. A text document may be better for the basis. You want to document the basis for the cost estimate, so that if someone asks where a cost came from, you can tell them. Engineering firms can help with this task.

For our example project, we might develop an estimate where the equipment costs are based on vendor quotes, the instrumentation costs are based on a combination of historical data and quotes, the piping and electrical material costs are based on current prices from the supply house, concrete and steel costs are based on budgetary prices from local contractors, and piping and electrical installation costs are estimated by the engineering firm based on Richardson and Means. You should explain where costs for outside services came from, for example a proposal from the engineering firm. And you will want to document the basis for items such as contingency and escalation, if applicable. The more detailed the cost estimate, the more detailed the basis document should be. Again, an engineering firm can help with this.

Like the scope document, the cost estimate can be used to prevent scope changes. If an item is not in the cost estimate, it is not in the project budget, and therefore not in the project. It also helps you document actual costs versus budgeted costs as the project progresses. If your project is over budget, management will want to know why. This information can also be valuable for future projects.

3. Project schedule

Every project, no matter how small, should have a documented schedule. Obviously, the schedule answers the question, "when" (or more often, "how soon"). The schedule may be as simple as a few milestones or a simple Gantt chart, but every project should have a schedule that is updated. A milestone schedule, especially in the early phases of a project, might look something like this:

Obtain charter approval	Jan. 31
Develop scope and estimate	Feb. 28
Project approval	March 15
Engineering	April 30
Equipment purchasing and deliveries	July 31
Construction	Oct. 31
Commissioning	Nov. 15
Startup	Nov. 30

Generally, as a project advances, more detail is included in the schedule. For example, the level of detail shown above would not be adequate for our example project after the initial scope-development phase. The Gantt chart is the most typical type of schedule, and Microsoft Project is a commonly used scheduling software, although you can create simple Gantt charts using Excel also. Figure 1 is an example of a preliminary schedule. Note that it still does not contain enough detail to really manage and control the project.

As the project progresses, the schedule needs to be updated. Management will want periodic updates on the project, including the schedule. Say for example, in the

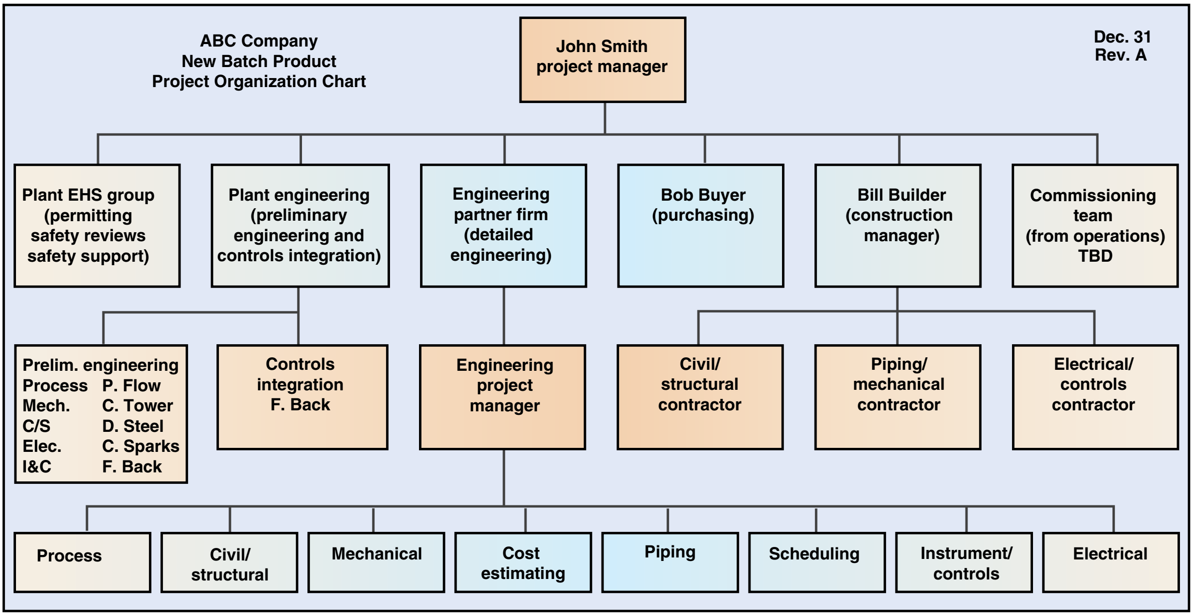


FIGURE 2. An organization chart clarifies who is on the project team

milestone schedule above, that your company has made commitments to customers to deliver the new product in December, immediately following the startup. Then you find out that tank deliveries are going to take one month longer than expected. That needs to be communicated up the line and a work-around may need to be put into place. In this case, the work-around may be that the product has to be made in the pilot plant, which may require overtime. Or, it may need to be toll manufactured, or some type of temporary storage may be required. You may also need to pay an expediting fee to meet the needed delivery date. Note that the work-around may impact the project budget and eat into your contingency. This would also need to be communicated to management.

In some cases, something happens to cause a schedule delay from which you cannot recover. In this case, the schedule needs to be adjusted to reflect the impact of that delay on other remaining tasks, and determine a new completion date. A schedule delay always needs to be communicated up the management line.

4. Organization chart

While this tool may sound obvious, the organization chart answers the question of "who." This can be important if your organization has limited resources to assign to the project, if you are using part-time resources, or if you are using third-party resources. The organization chart makes someone's assignment on the project "official" and having peoples' names on the organization chart may help you get the priority and commitment you need to get the project done. For example, if the plant maintenance engineer is responsible for the electrical design on your project, you might find it difficult to compete for his or her time. With any luck, the organization chart (along with the project schedule) might give you some leverage. Likewise, if you are using third-party resources, you can use the organization chart to remind people that you are having to use outside resources, which can require more effort to coordinate and control. This could also help justify the cost for those outside resources, since you are using them because no in-house resources are available. Figure 2 depicts a sample organization chart for our example project.

5. Action-item list

I run every project on which I work with an action-item list, also sometimes referred to as an open-items list, or sometimes an information-needs list (which is really a subset of the former). The action-item list can be used to keep track of anything on the project that needs to be done: information that is needed; decisions that are needed; or any action that is needed. It is different from the schedule in that the items on the action-item list are typically not important enough to be tasks on the schedule, but nonetheless, they are required to keep the project moving. As examples, say you need information from the maintenance staff on the existing tote/drum filling line, a decision on the location of the new tanks from operations staff, and verification from the plant control engineer that there is adequate I/O capacity in the control system — all by certain dates in order to keep the project on schedule. These would not likely be tasks on the project schedule, but they can be kept track of on the action-item list. And the action-item list can be used for your own tasks as well as those of others.

A common format is to use a spreadsheet with columns for items such as the following:

- Item number
- Description (such as "Need deci-

TABLE 1. A SIMPLE FORMAT FOR A RISK REGISTER

Item number	Risk description	Risk treatment	Potential cost	Probability	Risk cost (potential cost × probability)	Comments
1	Steel prices are currently very volatile	Try to order early to lock-in price	Potential 20% increast on two $50,000 tanks ($20,000)	Estimated to be 30%	$6,000	Need to size, specify and order tanks as early as possible. Could impact piping costs

sion on location of raw material and product storage tanks")
- Date entered
- Needed or requested from (name of specific person)
- Date needed (allowing the person reasonable time to respond, but also timely enough to keep project on schedule)
- Date received (to be able to show whether or not you are getting answers or decisions in time to keep the project on schedule)
- Comments (can be used to record a status or the final resolution)

Some formats use more column headings, and can become complicated. I prefer to keep them simple. If they get too complicated, they get too onerous to keep updated, and the action-item list should be updated at least weekly.

The action-item list has multiple uses. It serves as a tickler list for the project manager, so that key items are not forgotten. And, the dates help keep items prioritized and on-track. The list can be used to keep people accountable for providing information and actions needed for the project. So if one group or person is not responsive and is causing delays, the action-item list can provide leverage to try to get them to respond. And ultimately, it will provide a history of all these key items and decisions for record-keeping purposes.

6. Project execution plan

The project execution plan answers the "how" questions. How will the project be carried out? How will we do the engineering (in-house or go outside to an engineering contractor)? How will we buy the equipment (in-house purchasing resources or a third-party)? How will we contract for the construction (general contractor or multiple prime contractors)? How will we manage construction (in-house resources or a third-party)? How will we obtain any other outside services needed (surveying, geotechnical services, inspection and testing services and so on)? As you can imagine, the execution plan can get pretty detailed, and it often evolves along the way as the project gets more fully defined [*6*].

Developing a project execution plan will force the project manager to think through the entire project from start to finish. In doing so, this exercise will help capture potential costs and schedule impacts that need to be accounted for. For example, say that in our example project there are not enough in-house resources available to do all of the design, so an outside engineering firm will need to be engaged for the civil, structural and piping design. A firm must be selected, and this will need to be accounted for in the schedule and budget. Your corporate procedures may require that bids be obtained for these services, so just getting the engineering firm on board could require a lot of time and effort (see Ref. [*7*] and [*8*] for additional thoughts on this task).

The project execution plan also documents a basis for the project that could be helpful in the event that conditions change. For example, say that you intended to use an internal resource for the electrical design, and then find out that this resource is not available. You will then have to use an outside resource, which will likely impact your budget and schedule.

Another example may be that originally you intend to buy new tanks for the raw material and product storage, but then after the initial cost estimate, management decides to try to cut costs by looking into used equipment. The original execution plan (as well as the scope, schedule, and cost estimate) would document that new tanks were intended, and then would need to be revised to account for the change to used tanks. While this change may save the project money, it could take more time to find, inspect, buy, possibly clean and ship the tanks to the site. The schedule impact of this change would, therefore, also need to be evaluated. These steps should be mentioned in the revised execution plan.

As mentioned above, all steps in the project should be considered, including the following:
- Initial scoping
- Project approvals
- Permitting
- Design
- Safety reviews
- Procurement (of both equipment and contracts)
- Construction
- Commissioning
- Startup

As you can imagine, it is difficult to have a handle on all of these items at the beginning of the project. Some items may change as the project progresses, which makes the execution plan somewhat of an evergreen document. The idea, however, is to get a plan documented, reviewed and approved by management. That way it can serve as a basis in case it does change later.

7. Risk register

The risk register is an advanced tool that is a good idea for all projects [*1*]. Some companies are now even requiring risk registers as part of their project procedures. While contingency in a cost estimate is primarily intended to cover the "unknown unknowns," the risk register can help you iden-

TABLE 2. SUMMARY OF PROJECT TOOLS TO HELP TIE THEM ALL TOGETHER

Tool No.	Name	Questions Answered	Purpose	Utility for Project Manager
0	Project Charter	Why, what (on a high-level), and possibly when (such as target completion date)	Initiates project, defines objectives, authorizes resources to be spent	Provides management approval to obtain resources
1	Project Scope Document	What (in detail), and where	Defines what the project will provide, where it will be located	Scope control; prevent scope changes
2	Project Cost Estimate with Basis	How much does it cost, and where do the costs come from	Develops project budget	Budget control and reconciliation
3	Project Schedule	How long, when	Planning; determine sequential relationships and parallel activities and time required to execute project	Schedule control and reconciliation
4	Organization Chart	Who	Defines staffing and resources required	Planning; justification for and getting commitment on staffing and resources
5	Action Item List	What is needed and when	Keep track of information and tasks needed to progress the project	Reminder list; can show if not getting the information or decisions needed on a timely basis
6	Project Execution Plan	How	Overall project planning; also provides basis for cost estimate and schedule	Communication of overall project plan
7	Risk Register	What might happen to affect our plan	Planning; input to cost estimate, schedule, and possibly execution plan	Anticipating potential impacts of risks and planning mitigation

tify potential known risks and, by assigning probabilities, quantify a risk contingency. While a full description of risk assessment is a topic for a more advanced article, a simple example is given here.

In our example project, some known risks might include the following:

- Abandoned underground lines may exist in the area where we want to install the raw material and product tanks. Ideally, you'd like to know before you finalize your project, scope, budget and schedule, but for now let us say that you do not know.
- Tank fabricators are busy, deliveries are running longer than usual, and they might not meet delivery commitments.
- Steel prices are very volatile.

You can capture these risks in a risk register, assign probabilities, and quantify a risk contingency for the project. A simple format for a risk register would have headings and corresponding entries as shown in Table 1.

Once you have completed the risk register, the total risk cost, or some portion of that, could be entered into the project cost estimate as risk contingency, which then becomes part of your project budget.

Having items documented in a risk register shows good project planning. Since no one has a crystal ball, the entries may not be exactly right, but they show your management that you tried to account for the risks.

Final thoughts

Table 2 provides a quick summary of the documents (tools) discussed here. Many of them are related, so keep in mind that a change to the project may require the revision of several of these documents.

Planning and executing a project is a big undertaking. Using these tools from the beginning and throughout the course of a project will help make you and your project successful in terms of meeting objectives, budget and schedule. ■

Edited by Dorothy Lozowski

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Pressurized Piping: Sampling Steam and Water

Without proper systems, analysis of steam and water chemistry can provide erroneous results — with costly implications

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Corrosion and deposition in boilers, steam turbines and many types of process equipment are among the most expensive causes of outages in utility and industrial steam plants. Deposits and scale buildup on heat-transfer surfaces reduce efficiency, and when allowed to accumulate on steam turbines, such buildup can reduce the capacity. Corrosion-related failures can result in outages ranging from a few days to several months, depending on the affected systems, and can potentially cost tens of millions of dollars.

To reduce the risk of corrosion and deposition in water and steam systems, the standard practice is to monitor cycle chemistry and control impurity levels within industry- and manufacturer-recommended limits for the equipment. In steam plants, the chemical parameters of interest include: pH; conductivity; sodium; calcium; magnesium; chloride; sulfate; fluoride; phosphate; acetate; formate; propionate; total organic carbon (TOC); silica; copper; and dissolved and suspended iron (oxides). Typical target concentrations are in the range of <1 part per billion (ppb) to several parts per million (ppm) [1, 2].

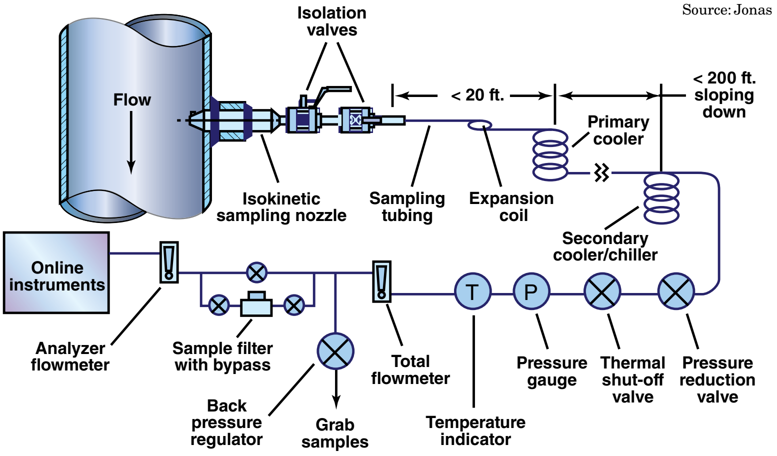

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FIGURE 1. This figure shows an example of a well-designed sampling system for extracting and conditioning a representative sample of steam or water. It includes isokinetic sampling, rapid condensation and cooling, pressure reduction, and process indicators, as well as safety devices to protect online instruments and plant personnel

Unfortunately, many utility and industrial steam plants do not have properly designed and operated sampling systems to monitor water and steam chemistry. In fact, in water chemistry and corrosion control audits, sampling problems are found in roughly 70% of all plants. As a result, operating decisions are often based on data that can have sampling errors as high as ± 1,000%. These errors, as well as data inconsistencies and concentration swings in the analytical results, become commonplace and are often ignored by plant personnel, preventing the timely identification of actual chemistry excursions. This article outlines the principles that must be considered when designing and operating water- and steam-sampling systems.

Sampling system design

To monitor systems for the ingress of impurities and for the production and transport of corrosion products, several cycle streams are sampled and analyzed, either continuously or periodically. Proper design of the sampling systems is critical in order to produce samples and analytical results that are representative of the sampled stream [3–9]. Problems with sample withdrawal, transport, collection and handling are often major sources of errors that can lead to incorrect or unnecessary corrective actions by operators. A meticulously performed chemical analysis is of little value if a bad sample is used. As shown in the box on p. 43, there are many potential causes of sampling errors, some of which can cause analytical results to be orders of magnitude higher or lower than the actual concentration in the process stream.

In high-purity systems, the measured concentration of impurities in many of the process streams is in the low parts-per-billion (ppb) range. At such low concentrations, the fluid being extracted is very sensitive to any deposition or chemical reactions within the sampling system. The extraction of non-repre-

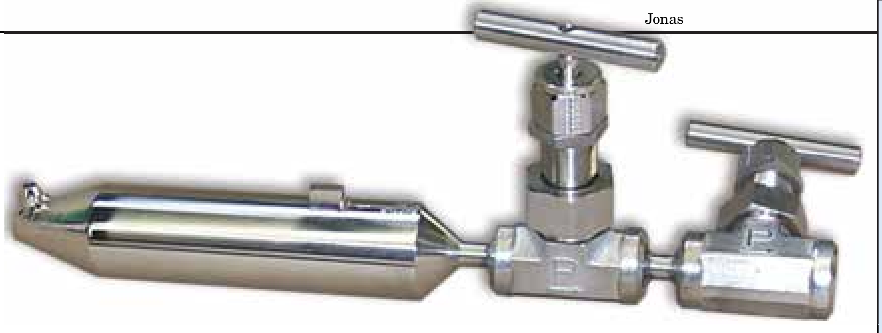

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FIGURE 2. **This weld-in style, single-port isokinetic sampling nozzle meets current ASTM standards for sampling water and steam. Flanged connections to the process pipe are also acceptable**

sentative samples can lead to large sampling errors [*3*]. Even in lower-purity systems, sampling errors due to improperly designed sampling systems can be significant.

A well-designed sampling system (Figure 1) consists of an isokinetic sampling nozzle (discussed below), isolation valves, sample tubing, a primary cooler (for steam and high-temperature liquid samples), a secondary sample cooler, pressure-reduction and total-flow-regulation valves, a thermal-shutoff valve (for process temperatures above 100°F), back-pressure regulator and sample drains.

Because steam impurities are easily adsorbed by magnetite (Fe_3O_4), the oxide buildup on the inner diameter of the sampling nozzle and tubing should be minimized. For this reason, all wetted components of the sampling system should be made from at least Type 316 stainless steel. Carbon and low-alloy steels should be avoided.

Deposit buildup in the sample lines can result in plugging of the sample line or seizing of sample isolation valves. Even when not directly affecting sample flow, deposits in the sampling system can affect the sample accuracy. Deposits can act as ion-exchange media and adsorb or release impurities during changes in the flow conditions. Even the best sampling-system design is still susceptible to deposition and plugging if the cycle chemistry at the plant is not maintained within industry standards, particularly when high concentrations of corrosion products (such as iron oxide or copper oxide) are present. Lengthy sample lines (for instance >100 ft) or low sample velocities (for instance < 4 ft/s) increase the probability of sample line blockage and can cause unacceptable time lags between sample collection and analysis. A sample flowing at 2 ft/s through 500 ft of tubing will take over four minutes to reach the analyzers.

Why isokinetic sampling?

Isokinetic sampling is the extraction of a representative portion of the process stream without altering the physical and chemical properties of the sample. In isokinetic sampling, all phases (solid oxides and precipitates, liquid droplets and vapor) of the sampled fluid enter the sampling nozzle with the same velocity vector (meaning the same velocity and direction of flow). The main reason isokinetic sampling is necessary is that the sampled stream is almost always a two-phase fluid (gas-liquid, gas-solid, liquid-solid) and the second phase typically has a very different chemistry composition than the steam or water [*2*]. In addition, the second phase (droplets or particles) typically has a different density and inertia compared to the primary phase (gas or liquid) and therefore would not be proportionally represented in a sample that was not withdrawn isokinetically. The benefits of isokinetic sampling have been verified during an Electric Power Research Inst. (EPRI) project [*3*] and through an independent analysis [*10*].

Sampling nozzle design

The design of the isokinetic sampling nozzle (Figures 2 and 3) is a critical part of the sampling system, and should be performed prior to the selection of the other sampling system components. As noted, if designed incorrectly, the sampling nozzle could provide a sample that is not representative of the conditions in the pipe. Proper sampling-nozzle design must consider the effects of flow- and vibration-induced forces on the nozzle, as well as the design pressure and temperature.

Prior to 2006, the ASTM Standard D1066 "Standard Practice for Sampling Steam" [*4*] included a multiport sampling nozzle, which — in its most basic form — consisted of a piece of pipe with multiple holes in it. The sampling pipe extended most or all of the way across the process pipe and was supposed to simultaneously sample from several locations across the diameter of the pipe. However, research has shown that such a multiport design operates non-isokinetically, is prone to plugging, and is susceptible to failure due to vibration [*3*].

In many piping applications, the flow in the process pipe is fully tur-

CAUSES OF SAMPLING SYSTEM ERRORS

Operators should be mindful of these common sources of sampling errors (in order of priority and impact):

- Sample withdrawal — Sample does not (1) represent the stream (due to wall effects, stratification, not isokinetic, or mixing issues), and (2) represent all phases (solid, liquid, gas)
- Deposition in the sample line (could also result in plugging)
- Release of built-up deposits into the sample stream (leading to spikes)
- High pressure drop leading to insufficient sample flow (typically due to long sample lines)
- Changes in sample flowrate (for instance, sampling system can take up to 6 hours to reach equilibrium from the start of sample flow)
- High sample temperature (can lead to pH and conductivity errors)
- Chemical reactions in sample lines or coolers (reduction of oxygen concentration, change in pH and so on)
- Corrosion of the sampling system may lead to generation of corrosion products (as a result of improper materials of construction)
- Filters in the system interfere with desire to sample suspended solids
- Sorption on sample tubing and suspended oxides may remove a portion of the chemical species being monitored

bulent. This results in a uniform velocity profile across the pipe and the stream is well mixed, so the composition is uniform across the pipe. This makes it unnecessary to sample at more than one location along the pipe diameter. In light of this, a single-port sampling nozzle was designed in the early 1990s [*3*]. The isokinetic sampling nozzles have a compact design, which has the advantage of being inserted only about 12% of the way into the pipe, compared to multiport nozzles, which must traverse most (if not all) of the diameter of the pipe. In fact, the single-port nozzle design was included in the ASTM standard in 1996. In 2006, it became the only recommended sampling nozzle design included in the standard.

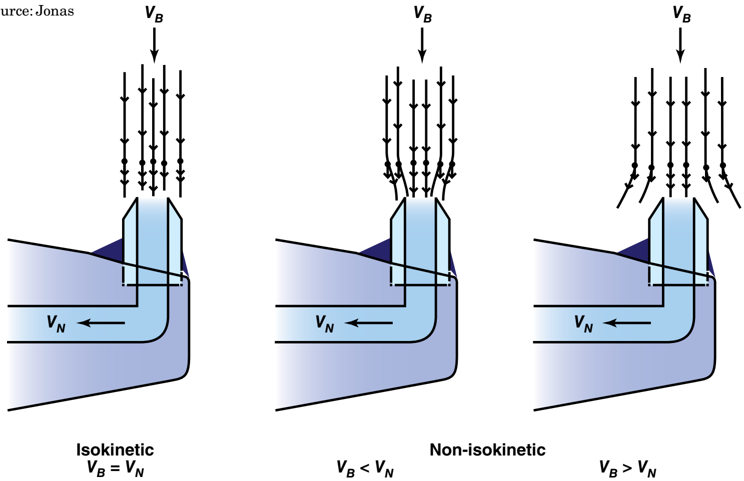
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FIGURE 3. Shown here is the ideal flow path of particulate matter and droplets into isokinetic and non-isokinetic sampling nozzles. In isokinetic sampling, the extracted fluid is representative of the composition in the process pipe, including particles and droplets. When the sampling is non-isokinetic, the concentration of particles and droplets can be higher or lower than that found in the process fluid. V_B = velocity of process fluid; V_N = velocity in the sampling nozzle

Transport of samples

Almost any fluid will leave or pick up some residue, both while flowing through a tube and while being stored in a container. As a result, any chemical analysis will become biased due to the loss or gain of contaminants. Several factors contribute to deposition on the tubing wall, including: crystallization resulting from solubility changes, settling due to gravity and hydrodynamic forces, and electrostatic attraction of charged particles [*6*].

In any sampling system, there will be an exchange of contaminants and particulates between the flowing sample and the sample line surfaces. Eventually, an equilibrium state will be reached. Whenever the sample is not in equilibrium with the surface, the sample composition will be changed from its original state. In general, the time for new sample tubing to reach equilibrium decreases with smaller tubing (due to decreased surface area) and increased sample velocity. Even when a sufficient sample velocity (say, on the order of 6 ft/s) is maintained, the equilibration process can take up to a month. It is for this reason that sample streams should flow continuously rather than be periodically started and stopped.

In order to minimize deposition in the sample lines and to reduce the time required to achieve equilibrium between impurities in the flowing sample and the tubing, the sample tubing after the primary cooler/condenser should be sized so that the sample flow velocity is maintained around 5–6 ft/s [*3–8, 12*]. Several studies have shown that both linear velocity and the Reynolds Number (Re; a unitless dimension that describes the amount of fluid turbulence) control the net deposition of particulate matter in sample lines [*13–17*]. Therefore, the sample line should be designed to achieve both turbulent flow (Re > 4,000) and proper velocity (5–6 ft/s).

In steam-sampling systems, one of the most critical design considerations is the size and length of the sample line from the sampling nozzle to the primary sample cooler/condenser. Long and oversized sample lines produce a significant pressure drop and heat loss from the extracted fluid. In general, both the temperature and pressure of the sample should be maintained right up to the primary cooler/condenser so that desuperheat and condensation occur together. To achieve this, the sample line should have approximately the same inside diameter as the isokinetic sampling nozzle, and the primary sample cooler should be located as close to the sample point as possible (less than 20 ft).

The total length of sample tubing should be as short as possible to limit both the pressure drop and the lag time from when the sample enters the isokinetic sampling nozzle to when it reaches the analyzers. Low sample residence time in the tubing is also preferred to limit chemical reactions, such as oxygen scavenging and sorption on oxides. The sample velocity should be maintained as constant as possible in the interest of maintaining equilibrium between deposition and re-entrainment of particles, and chemical equilibrium between the sample and deposits. In one research project [*16*], it was found that it took less than 30 days for a newly installed sampling system to reach equilibrium when the sample was flowing at 6 ft/s, compared to several years for a sample flowing at 1 ft/s.

In addition to the effects on sample purity, the use of larger-diameter tubing can result in an unnecessary waste of sample water (and additional energy required to heat and cool the fluid), require impractical sample-conditioning equipment,

TABLE 1. REYNOLDS NUMBER, SAMPLING RATE, ANNUAL VOLUME, AND PRESSURE DROP (ΔP) FOR WATER (T = 100°F) FLOWING THROUGH VARIOUS SIZES OF TUBING AT 5 FT/S

Outer dia. (OD), in.	Inner dia. (ID), in.	Wall thickness, in.	Reynolds Number, unitless	Required sampling rate, cm^3/min	Annual vol., gal/yr)	Estimated ΔP per 100 ft of tubing, psi
0.250	0.120	0.065	6.8×10^3	670	93,000	57
0.250	0.152	0.049	8.6×10^3	1,070	148,000	42
0.375	0.245	0.065	1.4×10^4	2,780	386,000	24
0.500	0.370	0.065	2.1×10^4	6,340	879,000	14

and place an extra and expensive burden on the makeup system. Table 1 compares sampling rate, Reynolds number, estimated pressure drop, and the annual volume of water consumed for several tubing sizes with a sample flow velocity of 5 ft/s. Typically, ¼-in. tubing with a sampling rate of 1,000 to 1,200 cm^3/min (condensed) is sufficient to provide for all online analyzers and grab sampling while maintaining the required flow velocities.

Additional considerations

When designing a sampling system, such as that shown in Figure 1, follow these recommended practices for each of the components discussed below:

Installation location for the sampling nozzle. The preferred location is in long, vertical sections of pipe, away from all flow disturbances (such as bends, valves, and so on) [*4, 6*]. Ideally, the sampling nozzle should be at least 35 internal pipe diameters downstream, and 4 pipe diameters upstream, of any flow disturbances. In many plants where space is at a premium, this is not possible, so it is recommended that the sampling nozzle be located where the ratio of its distance from the upstream disturbance to downstream disturbance is about 9:1. If a long vertical section is not available, the sampling nozzle may be installed in a long horizontal section, provided the sampling nozzle is installed on the top of the pipe between the "10 o'clock" and "2 o'clock" positions to prevent the possibility of water accumulating around the sampling nozzle during outages.

Isolation valves. These valves should be rated for the application temperature and pressure, and provide a minimum change of cross-section between the inside diameter of the isokinetic sampling nozzle and the orifice of the valve. Large changes in cross-section can result in deposition within the valve and may eventually lead to seizing of the valve, which can become a safety issue if the sample line is damaged during operation. Valves should be made of Type 316 stainless steel or a higher alloy. Because valves in steam and water service are susceptible to deposition inside the valve (particularly for steam service), it is recommended to always have two isolation valves.

Sample tubing between the isokinetic sampling nozzle and primary cooler. Such tubing should be as short as possible (not longer than 20 ft for steam systems) in order to minimize the pressure drop and reduce the possibility of impurity deposition in the sample tubing. The inside diameter of this sample tubing should be close to the inside diameter size of the isokinetic sampling nozzle, to minimize changes in cross-sectional area. This normally requires ¼- or ⅜-in. tubing for liquid water and medium- to high-pressure steam systems, and ½-in. tube or ½-in. pipe for low-pressure steam systems.

The sample line should include a series of bends or a coil to allow for any movement or expansion of the process pipe. Sharp-radius bends should be avoided. The tubing should be downward sloping along the entire length to eliminate any sections where condensed steam or water can accumulate and result in water hammer during startup.

Primary and secondary sample coolers. The coolers should have a counterflow design and be sized to ensure adequate cooling capacity, with allowances for reduced heat transfer due to scale buildup. The cooler tubing should be made from Type 316 stainless steel or Inconel.

Sample tubing after the primary sample cooler. This tubing should slope downward to allow for complete draining during outages, and have a minimum number of bends. It should be sized so that the sample flow velocity is 5 to 6 ft/s.

Pressure-reduction valve. Such a valve is used to reduce pressure and therefore control the flow of a cooled sample in order to protect online instruments. For sample pressure greater than 500 psig, the pressure reducer should be a rod-in-tube-type orifice or capillary [*5*]. For sample pressure less than 500 psig, the pressure reducer should be a needle valve.

Thermal shut-off valve. This valve protects personnel and downstream components by automatically interrupting sample flow when the sample temperature reaches a preset limit, in the event of an insufficient amount or loss of cooling water or a fouled sample cooler.

Pressure and temperature gages and flow indicator. Such devices provide the operator with verification that the system is working properly.

Back-pressure regulator. This regulator is used to maintain a slight pressure (~20 psig) in the sample tubing before the grab sample location. This will ensure proper flow to the online, chemical-analysis instruments.

Inline sample filters. These filters should be installed to protect online instruments during commissioning, or any other time when high concentrations of corrosion products (iron, copper) are present in the sample.

They should be installed downstream of the grab-sampling line (as shown in Figure 1), or must be bypassed when obtaining grab samples for iron and copper analysis.

Online analyzers. The sample flowrate, temperature and pressure must all be within the instrument manufacturers specifications. A chiller may be required in order to cool the sample streams to the proper temperature. ASTM D5127 requires that the sample temperature be 25±1°C when measuring pH, and ASTM D5391 requires that the sample temperature be controlled to 25±0.2°C when measuring conductivity if specialized temperature compensation is not available. Such strict temperature control may not be practical; therefore, the use of modern pH and conductivity analyzers that include temperature compensation algorithms may be an acceptable alternative.

Booster pumps. These pumps may be required for long sample lines (high pressure drop) or low pressure samples (condensate).

Once all of the sampling components are specified, the estimated pressure drop through the system should be calculated. The pressure drop throughout the entire sampling system (including primary and secondary coolers, tubing, valves and elbows) must be low enough to ensure that there is enough pressure to provide adequate flow velocity (5–6 ft/s) through the tubing to the online instruments and grab-“sample tap. A high pressure drop through the system could result in insufficient sample flow at the sample panel, or, the deposition rate in steam sample lines could be high, which could result in plugging of the sample line or a sample that is not representative of the conditions in the pipe. The design must also ensure that the maximum pressure recommended by the online instrument makers is not exceeded.

Commissioning of the system

After the sampling system is installed, the following tasks should be performed to ensure proper operation of all components:

- Check all sampling points to ensure proper location and sampling nozzle orientation
- Verify that all sample tubing and cooling water tubing is properly sized for the required flowrate
- Ensure that all valves and flowmeters operate properly
- Confirm the proper flowrate of cooling water to the primary and secondary sample coolers
- Check for leaks along the entire length of sample tubing including the sample panel
- Perform startup and calibration of all online instruments in accordance with the original equipment manufacturer’s (OEM) instruction manual
- Verify that online instrument readings agree with readings on the distributed control system (DCS) or other data-recording system, and that alarms are working properly
- Check sample flowrates
- Check sample temperatures after both primary and secondary sample coolers
- Check sample pressure
- Ensure flowrate through online instruments meets manufacturer requirement
- Check for any vibration at the sampling nozzle and along the length of the sample tubing.

Operation and maintenance

Once the sampling system is installed, proper operation and maintenance are required to ensure accurate sampling, including:

Total sampling rate and sampling time. The total sampling rate should be governed by the rate required for isokinetic sampling, which is a function of the sampling nozzle design and the process mass flowrate. Even if this sampling rate exceeds the requirements of online analyzers, the total sampling rate should be maintained by routing excess flow either through the grab-sample location to drain or to the condenser hotwell. For high-purity systems, it can take up to six hours of isokinetic sample flow to stabilize the sample chemistry. This time can be shorter for lower-purity systems, but for all sampling systems, continuous flow is preferred.

Grab samples. There are many opportunities for the grab sample to degrade during collection and storage. This is especially critical in samples for pH, conductivity, dissolved oxygen and hydrazine anal-

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ysis. Special preparation of grab samples or sample containers may be required, depending upon the type of analysis being performed. In some cases, chemicals are added to the container before the sample is added to prevent sample degradation (for instance, samples used for the analysis of iron or copper).

Collection methods for samples to be analyzed for pH, conductivity, dissolved oxygen, ammonia, hydrazine and organics must exclude contact between the sample and air. Storage methods and holding times of samples from collection to analysis require special consideration to avoid degradation of samples.

Calibration and maintenance. These steps should be routinely performed on all online instruments per the manufacturers' recommendations. Improperly calibrated and maintained instruments will result in inaccurate measurements, negating all engineering efforts to obtain representative samples.

Maintaining clean coolers. Periodic cleaning of the cooling water side of the coolers may be required to maintain proper heat transfer and sample temperature. The frequency of cleaning depends upon the scaling properties of the water used for cooling.

Sample tube cleaning. All sample tubing should be periodically cleaned by flushing or acid cleaning, or it should be replaced. The frequency of cleaning depends on the amount of impurities in the sample streams. One "quick and dirty" method to test the cleanliness of the sample line is to shut off the sample flow at the sample panel and then quickly turn on the flow to the maximum sampling rate. If the sample is brown or black, there are deposits in the sampling system.

Maintain safety. The sampling nozzle, attachment to the process pipe, valves and all welds should be periodically inspected for evidence of cracking and other forms of damage. For sampling wet steam and water, the section of process piping immediately downstream of the sampling nozzle should be periodically inspected for thinning by flow-accelerated corrosion. Installations that sample liquid water should be checked for cavitation. ■

Edited by Suzanne Shelley

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FIGURE 1. Rising temperature is often an indicator of operational problems in many types of machinery. The ability to gather and analyze temperature data in realtime using non-contact options can help operators to pinpoint issues and act accordingly

FIGURE 2. Problems such as overheated bearings can be diagnosed with a thermal imaging camera, which provides an alternative to direct-contact temperature sensors, especially for components that may be hard to reach, inaccessible or potentially hazardous

Rising temperatures and rapid or excessive heat buildup are useful markers for determining the operational health of many types of machinery and components that are used in a wide array of industrial and manufacturing settings. The types of mechanical and electrical systems for which temperature increases often signal problems include (but are not limited to): rotating machinery, such as motors, turbines, compressors, and their bearings, couplings and gearboxes; other types of process equipment, such as pumps, valves, heat exchangers, steam traps, heaters, conveyors belts, rollers, furnaces and more; steam and electrical heat-tracing systems; insulation on pipes and vessels; refractory lining systems for high-temperature systems and much more.

Because equipment malfunctions and abnormal or fault conditions in mechanical and electrical systems are often forewarned by a rise in temperature, the ability to gather and analyze temperature data in realtime can often help operators to both pinpoint existing performance-related issues and identify the onset of incipient problems. These problems can be caused by an array of issues, including wear, imbalance, misalignments, insufficient cleaning or lubrication, friction and electrical problems.

The traditional approach to temperature monitoring in industrial settings relies on direct-contact temperature sensors, such as thermocouples and resistance temperature detectors (RTDs). While these devices are certainly proven and accurate, they are not appropriate for use with certain types of equipment components or in some types of industrial settings.

By contrast, remote or non-contact temperature-measurement devices, such as infrared thermal-imaging cameras and infrared thermometers (IRTs) allow useful temperature data to be easily gathered from remote locations and thus offer a useful alternative to direct-contact temperature sensors. The ability to safely carry out temperature sensing from a distance, using either a thermal camera or an IRT, is particularly useful for machinery components and systems that may be hard to reach, inaccessible, or potentially hazardous. In this way, these temperature-monitoring devices help to enable realtime temperature measurement while ensuring worker safety (Figures 1 and 2).

Technology options

The two types of remote thermal-sensing options — infrared thermal-imaging cameras and IRTs — are widely used for temperature assessment in industrial and manufacturing facilities. In addition, two different types of IRTs are available — conventional IRTs, and so-called scanning IRTs. Used separately or together, these devices can help users across numerous industry sectors to quickly and easily assess the thermal condition of machinery, process systems, pipelines and more.

Conventional IRTs are best suited for applications that require accurate spot-temperature readings, while scanning IRTs and thermal cameras are useful for applications for which knowing the absolute temperature of a surface is less important than knowing the

FIGURE 3. Thermal-imaging cameras measure the surface temperature of the objects or areas being analyzed in terms of the amount of infrared (IR) energy that is emitted, transmitted or reflected by the object. The data can then be rendered as still or video images to help operators interpret the result

FIGURE 4. Designed with an easy-to-use pistol grip, thermal-imaging cameras are used to diagnose hot spots in machinery systems

temperature of a particular surface relative to other surfaces around it. The primary advantage of a thermal camera is its ability to display the thermal spectrum of an entire area, as seen in Figure 3.

Infrared thermal-imaging cameras. Portable thermal-imaging cameras are easy to use, and typically come with a pistol-grip design, as seen in Figure 4. They use infrared-imaging techniques to measure the surface temperatures of the objects or areas being analyzed and can render the data in the form of two-dimensional images or videos images to illustrate the data. Specifically, these specialized cameras measure surface temperature in terms of the amount of infrared (IR) energy that is emitted, transmitted and reflected by the object or area being analyzed. The temperature data are displayed as an IR heat spectrum, using a range of colors that are correlated to specific temperature ranges. Today's thermal cameras have great sensitivity, and provide measurement accuracies of up to ±2°F.

Thermal cameras produce a thermal signature or thermogram, which is a two-dimensional visual display that depicts the relative temperature variations across the object's surface. These images allow operators to quickly pinpoint problem areas, since temperature excursions, such as areas of heat loss or heat gain relative to the surroundings, are easily displayed through color variations in the rendered image.

Such visual displays of relative temperature variations across the surface of the objects gives operators and technicians unprecedented insight into the health of equipment and systems, and help to address emerging problems efficiently. Thermograms are especially useful when thermal imaging is used as part of regular inspections, because they allow engineers to quickly recognize changes that may signal an emerging problem. Thermal images that are captured and analyzed over time for the same component (for instance, a given motor or pump) can help users to identify locations of incipient malfunction or progressive wear or deterioration.

Creating such a record of heat buildup due to deteriorating conditions allows operators or technicians to dispatch the most appropriate intervention in a timely manner. These interventions include detailed inspection, troubleshooting and diagnostic efforts, and strategic maintenance and repair activities. Because thermal imaging is carried out at a distance, it enables the capture of thermal data from components that are in remote or hazardous areas, thereby ensuring worker safety.

Infrared thermometers. IRTs are portable, non-contact devices — again, typically with a user-friendly, pistol-grip design. IRTs use a special lens to focus the thermal radiation that is being emitted by the object (in the form of IR energy) onto an IR sensor. The embedded software correlates those IR readings to the temperature of the object using information about the material's emissivity. Like thermal imaging cameras, IRTs offer an ideal way for operators to determine the temperature of hot or cold surfaces remotely, which is especially useful for inaccessible or hard-to-reach objects or areas.

As noted earlier, two types of IRTs are available — conventional "spot" IRTs and so-called scanning IRTs. Scanning IRTs allow users to scan an entire area or system and quickly identify those sections where there is a significant temperature differential between the actual temperature of that section and a pre-set temperature setpoint value that the user has programmed into the device.

Using a conventional IRT with an appropriate distance-to-spot (D:S) ratio — one that allows the measurement "area" to be entirely focused within the object being measured — plant personnel can determine the temperature of an object at a single spot. A built-in laser-beam sighting source helps the user to focus the device on the target precisely, to ensure measurement accuracy.

While conventional IRTs are useful for remotely gathering point-source data about the absolute temperature of a given spot, scanning IRTs are useful for applications where it is not necessarily important to determine the absolute temperature of a surface, but it is useful to determine the relative temperature of a surface or area compared to its surroundings.

Today's scanning IRTs are not only very affordable (typically under a hundred dollars, compared to more than a thousand for thermal cameras), they are also extremely easy to use. With a point-and-shoot design, the user first establishes a baseline temperature that is appropriate for the application, after which an acceptable bandwidth or tolerance range is set — for example, ±10 degrees, although tighter tolerances of ±1 or ±5 degrees are possible.

When the trigger on a pistol-grip scanning IRT is squeezed and the device is moved slowly across the target area, the device uses a combination of sound (in the form of slower versus faster beeping sounds) and colored lights (for example, red for above range, green for within range, and blue for below range) to alert the user to any location where the temperature falls outside of the user-specified threshold values that define the setpoint range. The IRT will also provide an absolute temperature reading for that particular spot.

While scanning IRTs do not produce a thermal image, they do provide a quick, easy, and relatively inexpensive way for facility personnel to assess specific mechanical assets and identify those problem areas that may require closer inspection.

A valuable investment

While individual thermal cameras typically cost more than a thousand dollars, they can be a strategic investment — and will easily pay for themselves over a short amount of time if their use prevents a catastrophic failure.

As noted, the use of remote, IR-based thermal sensing to inspect, troubleshoot, diagnose and rectify problems with specific equipment in realtime can help facility operators to improve the efficiency and effectiveness of both component-specific and plant-wide operation and maintenance (Figure 5). Such improvements provide a number of opportunities for long-term savings and payback. For instance:

- The costs associated with unplanned downtime in industrial facilities, such as manufacturing plants and chemical process facilities can be greatly reduced when thermal imaging is used to improve preventive and predictive maintenance tasks
- Proactive troubleshooting and diagnostic intervention can help to decrease the likelihood of expensive or catastrophic equipment failures — especially important when considering mission-critical assets
- The ability to plan and execute more-strategic repairs helps to cut material and labor costs and extend equipment life, thereby helping to reduce both operating and capital budgets
- Increased uptime allows the facility to maximize its throughput capacity, product yields and profitability. The ability to carry out strategic maintenance activities helps to not only save money, but improve plant and personnel safety and environmental performance

FIGURE 5. When operators are able to monitor the thermal profile of equipment and systems using a remote monitoring technique, they can plan for the most appropriate and timely intervention to address a deteriorating condition

Best practices

There are several ways to make best use of thermal-imaging data. Trending opportunities can be used to the engineer's advantage. For instance, the thermal signature from a given component, such as a particular pump that may be suspected of having a problem, can be compared to the thermal signature of similar pumps in the facility. This will help to evaluate its condition relative to other equipment with comparable operation.

In addition, the thermal images generated for a given mechanical asset (say, a particular motor), can be strategically captured and cataloged over time in specific intervals. This record can provide timely indications of deteriorating conditions and help the operator to make reasonable predictions about the rate of future deterioration, so that the required action — be it maintenance, repair or replacement — can be carried out, at the appropriate time, in the most cost-effective manner.

When practical, it is a good idea to carry out baseline thermal-imaging inspections on new components, to establish baseline or reference images that represent the component's ideal state under normal working conditions. Going forward, any departure from normal temperatures that appear in the thermal images produced for the unit would signify trouble spots that require closer inspection.

Proper training and certification are extremely beneficial when using IRTs and thermal-imaging cameras. While these devices are typically simple to operate and provide data and images that are easy to interpret, both rely on sophisticated technology. As such, to ensure the most accurate results, users should gain a good working knowledge of the capabilities and limitations of these tools through proper training and certification. Without proper training, the accuracy of the resulting thermal data and images could be compromised. Following vendor-recommended operating guidelines and proven industry best practices is a must for data confidence.

Today, a variety of third-party groups offer training and certification in the proper use of thermal-imaging cameras, including the American Society for Nondestructive Testing (Columbus, Ohio; www.asnt.org), the Academy of Infrared Training (Bellingham, Wash.; www.infraredtraining.net), the Infraspection Institute (Burlington, N.J.; www.infraspection.com), The Snell Group (Barre, Vt.; www.thesnellgroup.com) and others.

Choosing the right thermal imaging camera for the environment has an effect on the equipment's ability to best collect accurate data. Thermal imaging cameras are widely used to carry out energy-efficiency studies and audits in residential, commercial and business settings, by helping to identify areas through which heated or cooled air is escaping from a building. Industrial facilities can also use these devices to carry out energy audits to identify further opportunities to reduce operating costs.

When this is done, users should note that regional climate variations can impact what time of year the use of a thermal imaging camera will be most effective. For instance, in northern climates, the use of thermal imaging to carry out energy audits at a facility tend to be most accurate when carried out during winter months (when the temperature differential between indoor and outdoor temperatures is the greatest) and temperature differentials resulting from the unwanted ingress or escape of heated or cooled air will be most easily identified by the thermal camera or scanning IRT assessment. By contrast, in southern climates, the summer months tend to guarantee the biggest temperature differential between ambient outdoor temperatures and air-conditioned settings.

This potential seasonal “limitation” can be somewhat overcome by selecting a higher-resolution thermal camera. Today, a variety of thermal cameras — with a range of prices and image-resolution capabilities — are available. Relatively low-end models have sensors with a resolution of 60×60 pixels. Mid-range units have a resolution on the order of 160×120 pixels, and high-end thermal cameras offer a resolution of 360×280 pixels.

While lower-resolution thermal cameras may be available at a lower cost, the desire for cost savings alone may “cost” the buyer in the long run by limiting the number of months over which the camera can be reliably utilized to carry out energy audits and other types of thermal inspections. In general, the higher the resolution of the thermal camera, the more reliably it can depict a thermal difference when carrying out a thermal assessment — even during those times of the year when the temperature differential between indoor and outdoor temperatures is relatively narrow. By investing in a higher-resolution camera, users will be assured of greater sensitivity and easier thermal assessments no matter what climate or time of year. This helps to ensure more accurate results and faster payback for the camera itself.

Another important factor to con-

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FIGURE 6. Infrared thermometers let users determine the temperature of a specific point on hot or cold surfaces remotely, which is especially useful for inaccessible or hard-to-reach objects or areas. D:S ratio is an important feature to consider when choosing an IRT

sider when using thermal cameras and IRTs is the relative emissivity values of the materials being surveyed. Emissivity is a measure of an object's ability to absorb or reflect radiation in the infrared range of the electromagnetic spectrum. As a simplifying assumption, many thermal cameras have fixed emissivity values that are associated with certain commonly encountered materials programmed into the control software.

However, today's more-sophisticated thermal-imaging cameras allow the user to make adjustments to the emissivity settings, to more accurately characterize the actual emissivity values of the materials being analyzed. Such values can often be found in published books and reference articles. This flexibility can help users to improve the accuracy of the resulting thermal images.

Certain surfaces, such as highly reflective metals, have very low emissivity values and cannot be measured accurately using IR-based temperature-measurement techniques. To overcome this problem and improve the utility and accuracy of IR-based thermal cameras and thermometers, industrial operators often paint the target surfaces or cover them with electrical tape. This raises the emissivity values of the components and improves the accuracy of the IR-based thermal imaging techniques.

When it comes to evaluating different IRT models, an important concept to consider is the distance-to-spot (D:S) ratio (Figure 6). This characteristic of the device provides a measure of the optical resolution that a particular unit can provide. Every IRT model has a stated D:S ratio, which determines the distance for which the device will provide the most accurate temperature reading as well as the diameter of the imaging area. For instance, most standard IRTs have a D:S ratio of 8:1. This indicates that an IRT 8 in. away from the object can accurately measure the temperature at a spot that is 1 in. in diameter. Similarly, an IRT that is 48 in. away from a target will measure the temperature within a circle that is 6 in. in diameter.

Units with a D:S ratio of up to 100:1 are also available. In general, the higher the D:S ratio of the device, the smaller the zone for temperature capture, because less of the surrounding area is involved in the measurement. IRTs with higher D:S ratios also provide for more accurate readings to be gathered from greater distances.

Closing thoughts

Remote, non-destructive, thermal-sensing techniques, using IR thermal cameras and scanning or conventional IRTs, provide useful alternatives to direct-contact temperature devices based on RTDs and thermocouples. They provide useful information on temperature excursions that are often the precursor to operational problems, allowing users to plan the most strategic predictive and preventive maintenance activities and to carry out the most cost-effective repairs and upgrades. Such efforts can help to optimize the productivity and reliability of the mechanical assets, maximize the uptime of the facility, and minimize downtime-related losses and expenses and reduce the risk of catastrophic equipment failures. And, remote IR-based temperature monitoring lets facility personnel carry out such surveillance without shutting down the machines, interrupting the process or putting themselves in harm's way. This maintains equipment reliability, the facility's desired productivity levels, as well as personnel safety, and thereby helps to protect the facility's bottom line. ■

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Fractionation Column

Learning more about distillation

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

FRI's membership has been growing steadily since 2006. As a result, I have more bosses every year; at present, 78. I receive input from them in several ways. They attend quarterly meetings. They respond to surveys and votes. They send emails. They call. Primarily, this column describes the projects that are presently of the most interest to the membership.

In 2013, 8-ft-dia. two-pass valve trays were tested. The primary focus was turndown performance. In 2014, there will be a five-month project, where high-surface-area structured packings (500 and 350 m2/m3) will be installed in the low-pressure column. Four different distributors will be employed, with pour point densities ranging from 60 to 220 pour points per square meter (ppts/m2). During some of those tests, certain distributor holes will be plugged to determine the impacts on efficiencies and to determine the ability of gamma scans to identify the maldistributions.

There are other projects high on the members' priority lists. Picket-fence outlet weirs have already been studied at FRI, at least twice, most recently with 70% blockage. On trays with low liquid rates, pickets can be used above outlet weirs to hold liquid on the trays and increase efficiencies. In the near future, picket-fence weirs with 50 and 95% blockage will be studied. Alongside those tests, spray factor analyses will be performed.

Tray decks have employed push devices going back to the 1960s, if not before. Slots, jet tabs, moving push valves and fixed push valves have been employed to eliminate froth stagnancies and froth height gradients, and to reduce froth heights. Many of the patents on such devices have expired. FRI's study of such devices might include computational fluid dynamics (CFD). The easier question: How much horizontal push do the deck devices provide? The more difficult question: How much push is required? Maybe the most important question: How much push is excessive, leading to horizontal fluidization?

On trays, downcomer velocity flood and choke flood are not as well understood as jet flood and froth-height flood. FRI's high-pressure column is capable of functioning at 500 psia. That column will be equipped with trays whose downcomers are purposely too small; the decks will probably contain moving valves. The downcomer flood points will be sought.

On an increasing basis, trays are being equipped with de-entrainment devices, such as 3-in.-thick mesh attached to the underside of trays. For this FRI project, various de-entrainment devices will be tested, including mesh, structured packing, cyclones and chevrons. A Phase Doppler Interferometer from Artium Technologies will be employed, with appreciable assistance from Oklahoma State University personnel, to determine droplet size and velocity distributions underneath the devices (for more on this, see: The science of droplets, *Chem Eng.*, p. 73, September 2013).

FRI's Design Practices Committee is as busy as always. Volume 5 of the FRI Handbook now contains a large chapter devoted to all aspects of packing distributors. The committee's present focus is a set of recommendations regarding two-phase feeds and draws. The entire FRI membership is forever indebted to these 18 globally known experts who willingly donate their time on the committee. ■

Mike Resetarits

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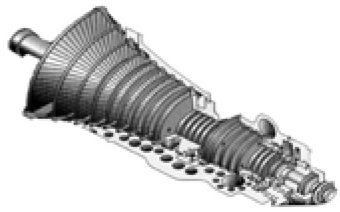

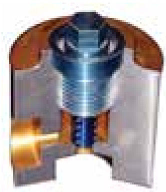

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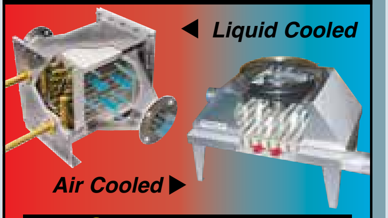

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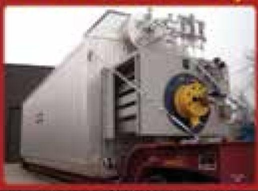

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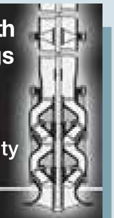

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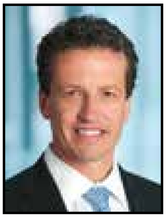

Scheu


Festge

Bioformix, Inc. (Cincinnati, Ohio), a manufacturer of energy-efficient, sustainable polymer platforms, names *Jeff Uhrig* senior vice president of corporate strategy.

Nadege Laborde becomes president of the industrial biotech business unit of **Novasep** (Pompey, France), a supplier of manufacturing solutions for the life sciences industry.

Greg Scheu, who is currently responsible for marketing and customer solutions for the executive committee (EC) of **ABB** (Zurich, Switzerland), will lead the company's acquisition-integration efforts and will take over responsibility for North America.

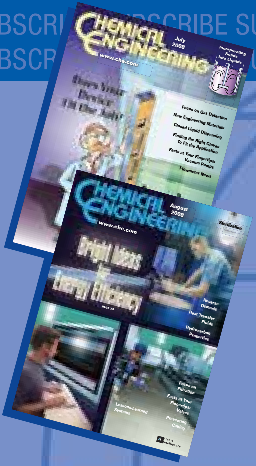
Steve Edwards becomes chairman, president and CEO of **Black & Veatch** (Overland Park, Kan.). He succeeds *Len Rodman*, who is retiring.

Reinhold Festge, managing partner of Haver & Boecker (Oelde, Germany) becomes president of the **VDMA** (German Engineering Federation; Frankfurt, Germany). He will serve a three-year term.

Archroma (Reinach, Switzerland), a producer of color and specialty chemicals, names *Stephan Sielaff* chief operating officer.

Dow Corning (Midland, Mich.), appoints *Tang-Yong (TY) Ang* vice president of the company's compound semiconductor solutions business unit. ■

Suzanne Shelley



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BUSINESS NEWS

PLANT WATCH

Praxair starts up carbon-dioxide purification plant at Honeywell site

December 10, 2013 — Praxair, Inc. (Danbury, Conn.; www.praxair.com) has started up its new carbon-dioxide (CO_2) purification facility at the Honeywell Resins & Chemicals site in Hopewell, Va. Under a longterm agreement, Praxair will purchase CO_2 from Honeywell (Morristown, N.J.; www.honeywell.com). Praxair's new facility purifies and liquefies around 400 metric tons per day (m.t./d) of CO_2.

Sonatrach and GTC near completion on new *p*-xylene plant in Algeria

December 9, 2013 — Sonatrach (Algiers, Algeria; www.sonatrach.com) is nearing completion of a *p*-xylene crystallization plant at its integrated petroleum refinery and petrochemical site in Skikda, Algeria. The plant's core units will license process technology from GTC Technology (Houston; www.gtctech.com). Samsung Engineering Co. (Seoul) provided engineering, procurement and construction services for the plant.

Clariant announces second expansion at its ethoxylation site in Texas

December 4, 2013 — Clariant (Muttenz, Switzerland; www.clariant.com) has announced the second expansion of its ethoxylation site at Clear Lake in Pasadena, Tex. Following the first expansion in 2012, this new expansion brings the overall ethoxylation capacity to more than 125,000 m.t., up from the present capacity of 95,000 m.t. Products manufactured include high-molecular-weight polyethylene glycols, alcohol ethoxylates, sodium isethionates and ethoxylated specialties.

BASF produces first commercial volumes of bio-based butanediol

November 27, 2013 — BASF SE (Ludwigshafen, Germany; www.basf.com) has produced its first commercial volumes of 1,4-butanediol (BDO) from renewable raw material, using a patented fermentation technology from Genomatica (San Diego, Calif.; www.genomatica.com), which uses dextrose as a feedstock. BASF is offering this product to customers for testing and commercial use.

Sasol selects Technip as FEED contractor for U.S. gas-to-liquids facility

November 25, 2013 — Sasol Ltd. (Johannesburg, South Africa; www.sasol.co.za) has selected Technip S.A. (Paris; www.technip.com) as the primary contractor for the front-end engineering and design phase of its proposed gas-to-liquids facility in Louisiana. The estimated project cost is between $11 billion and 14 billion.

Vencorex joint venture to build isocyanate plant in Thailand

November 20, 2013 — Vencorex (Saint-Priest, France; www.vencorex.com), an isocyanate joint venture (JV) between PTT Global Chemical of Thailand, and Sweden's Perstorp Group, is expanding its global capacity by establishing a new production unit in Thailand. With a capacity of 12,000 m.t./yr, the new plant will begin production in 2015.

GE and Carbon Holdings sign agreement for Egypt's largest petrochemical plant

November 19, 2013 — GE (Fairfield, Conn.; www.ge.com) and Carbon Holdings have signed an agreement worth $500 million to provide technology and equity support to the greenfield naphtha cracker and olefins complex project of Tahrir Petrochemicals in Ain Sokhna, Egypt. With a capacity of 1,360,000 m.t./yr of ethylene and polyethylene, as well as significant quantities of propylene, benzene, butadiene and linear alpha olefins, the plant is billed as the world's largest liquid naphtha cracker.

Lanxess starts up newly expanded cresol plant in Germany

November 15, 2013 — Specialty chemicals company Lanxess (Cologne, Germany; www.lanxess.com) has completed the expansion of its cresol production plant in Leverkusen, Germany, and has now begun operating a newly constructed reaction system as well as a second distillation column. The expansion increases cresol capacity by 20%. Lanxess has invested around €20 million in the new units.

Airgas to build new air-separation unit near Chicago

November 15, 2013 — Airgas, Inc. (Radnor, Pa.; www.airgas.com) has announced that the Prologis International Centre South in Minooka, Ill. will be the site for its new air-separation unit (ASU) in the Chicago area. Construction of the facility is scheduled to begin in February 2014. The ASU will produce more than 450 m.t./d of oxygen, nitrogen and argon, with production expected to begin in the summer of 2015.

MERGERS AND ACQUISITIONS

Brenntag to acquire a portion of Kemira's operations in Denmark

December 9, 2013 — Brenntag AG (Mülheim an der Ruhr, Germany; www.brenntag.com) has signed an agreement to acquire a part of the operational business of Kemira Water Denmark A/S. Brenntag will take over the distribution of caustic soda, sulfuric and hydrochloric acids, solvents and packed coagulants. The acquired business generated total sales of approximately €15 million in 2012 and the parties have agreed not to disclose further financial information.

BASF divests polyvinylchloride modifier business to Kaneka

December 9, 2013 — BASF has signed a contract to sell its Vinuran polyvinylchloride (PVC) modifier business to Kaneka Belgium N.V., a subsidiary of Kaneka Corp. (Osaka, Japan; www.kaneka.com). The parties have agreed not to disclose the purchase price or any further financial details.

Amyris and Total form JV for renewable diesel and jet fuel

December 5, 2013 — Amyris, Inc. (Emeryville, Calif.; www.amyris.com) and Total (Paris; www.total.com) have announced the formation of Total Amyris BioSolutions B.V., a 50-50 JV that now holds exclusive rights and a license to produce and market renewable diesel and jet fuel from Amyris's renewable compound farnesene.

Kuraray to acquire DuPont Glass Laminating Solutions/Vinyls

November 26, 2013 — Kuraray Co. (Tokyo; www.kuraray.co.jp/en) and DuPont (Wilmington, Del.; www.dupont.com) have signed a definitive agreement for DuPont to sell Glass Laminating Solutions/Vinyls, a part of DuPont Packaging & Industrial Polymers, to Kuraray for $543 million, plus the value of the inventories. The sale is expected to close during the first half of 2014, pending customary regulatory approvals.

Tessenderlo to sell phosphate business to Belgium's EcoPhos

November 20, 2013 — Tessenderlo Group (Brussels, Belgium; www.tessenderlo.com) has signed an agreement to sell its Aliphos feed phosphate business to EcoPhos, a Belgian producer and developer with feed phosphate as its core activity. ■

Mary Page Bailey

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January 2014; VOL. 121; NO. 1

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Economic Indicators

2011 🟦 2012 🟩 2013 🟧

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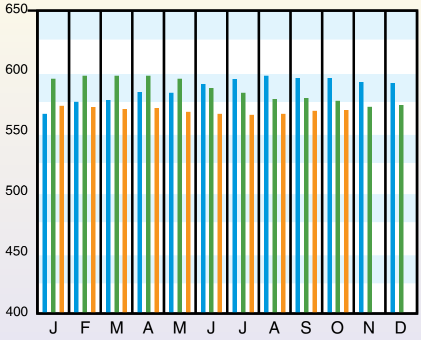
CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957–59 = 100)	Oct.'13 Prelim.	Sept.'13 Final	Oct.'12 Final
***CE* Index**	567.7	567.3	575.4
Equipment	686.6	686.2	698.2
Heat exchangers & tanks	620.0	618.3	638.5
Process machinery	655.8	654.7	658.4
Pipes, valves & fittings	874.5	875.3	899.4
Process instruments	411.9	411.2	424.4
Pumps & compressors	924.7	924.3	929.0
Electrical equipment	513.8	513.7	512.2
Structural supports & misc	744.1	747.1	734.2
Construction labor	322.2	321.7	323.7
Buildings	533.9	533.4	525.4
Engineering & supervision	325.6	324.6	327.9

Annual Index:

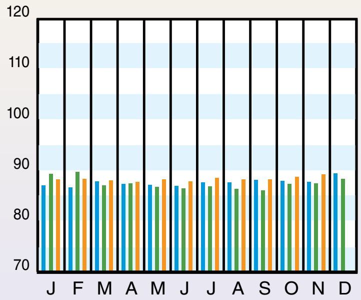
2005 = 468.2
2006 = 499.6
2007 = 525.4
2008 = 575.4
2009 = 521.9
2010 = 550.8
2011 = 585.7
2012 = 584.6



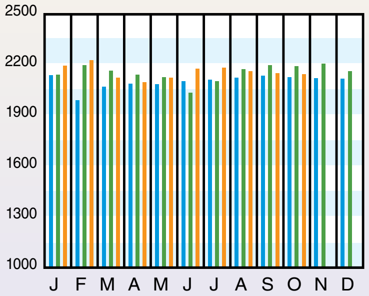
CURRENT BUSINESS INDICATORS*

	LATEST		PREVIOUS				YEAR AGO	
CPI output index (2007 = 100)	Nov.'13	= 89.2	Oct.'13	= 88.7	Sep.'13	= 88.2	Nov.'12	= 87.4
CPI value of output, $ billions	Oct.'13	= 2,145.1	Sep.'13	= 2,152.1	Aug.'13	= 2,164.9	Oct.'12	= 2,194.4
CPI operating rate, %	Nov.'13	= 75.3	Oct.'13	= 74.9	Sep.'13	= 74.5	Nov.'12	= 74.3
Producer prices, industrial chemicals (1982 = 100)	Nov.'13	= 291.5	Oct.'13	= 296.3	Sep.'13	= 299.9	Nov.'12	= 296.5
Industrial Production in Manufacturing (2007 = 100)	Nov.'13	= 97.2	Oct.'13	= 96.6	Sep.'13	= 96.1	Nov.'12	= 94.5
Hourly earnings index, chemical & allied products (1992 = 100)	Nov.'13	= 156.5	Oct.'13	= 156.6	Sep.'13	= 156.6	Nov.'12	= 153.9
Productivity index, chemicals & allied products (1992 = 100)	Nov.'13	= 107.3	Oct.'13	= 107.1	Sep.'13	= 105.9	Nov.'12	= 105.2

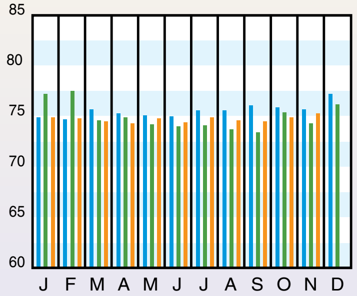
CPI OUTPUT INDEX (2007 = 100)



CPI OUTPUT VALUE ($ BILLIONS)



CPI OPERATING RATE (%)



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

HIGHLIGHTS FROM ACC'S YEAR-END ECONOMIC REPORT

Revenues from sales of chemicals in the U.S. are projected to top $1 trillion by 2018, according to economic analyses conducted by the American Chemistry Council (Washington, D.C.; www.americanchemistry.com) and discussed in its Chemical Industry and Outlook report for the end of 2013.

"The consensus is that U.S. chemical output will improve during 2014 and into 2015," the report states. Projections for gains in chemical production are 2.5% for 2014 and 3.5% for 2015, after smaller gains of 0.1% and 1.6% in 2012 and 2013, respectively. Strong growth is expected for plastic resins and organic chemicals, with growth helped by reviving export markets, ACC says.

"Looking ahead to 2015 and beyond, significant shale-driven chemical capacity will start to come online and generate faster growth, especially along the Gulf Coast," ACC says.

Aside from chemical production, 2013 also saw expansion of employment in the chemical industry, by 1.3%. Continued addition of jobs is expected in the industry through 2018, the report says.

The ACC report also examined chemical production globally. Overall, worldwide production likely advanced only 2.4% in 2013, held back by recession conditions in Europe and slowdowns in China and other East Asian nations, the ACC report says, a growth rate that is lower than those for 2012 and 2011. However, the ACC analysis predicts that global chemical production growth will improve to 3.8% in 2014 and 4.1% in 2015.

Low-cost feedstock and energy afforded by the availability of shale gas portend plant and equipment investment in the U.S. "The United States is being favorably re-evaluated as an investment location," the ACC report says, and "petrochemical producers are announcing significant expansions of capacity in the U.S., reversing a decade-long decline." Through early December 2013, over 135 new chemical production projects, valued at $90 billion, have been announced, according to ACC estimates.

R&D spending by U.S. chemical companies likely increased 0.5% in 2013, the report says. ❑

CURRENT TRENDS

Preliminary data for the October 2013 CE Plant Cost Index (CEPCI; top; the most recent available) show a slight (less than 0.1%) increase in the overal index, as well as small increases in most of the index subcategories. The Pipes, Valves and Fittings subindex and the Construction Labor subindex were the exception, showing small decreases while the others rose by small margins. The current CEPCI value stands at 1.33% lower than the value from a year ago. The year-over-year gaps are continuing a months-long trend of narrowing. Meanwhile, updated values for the Current Business Indicators from IHS Global Insight (middle) saw a modest increase in the CPI output index, and a decrease in the value of output. ❑

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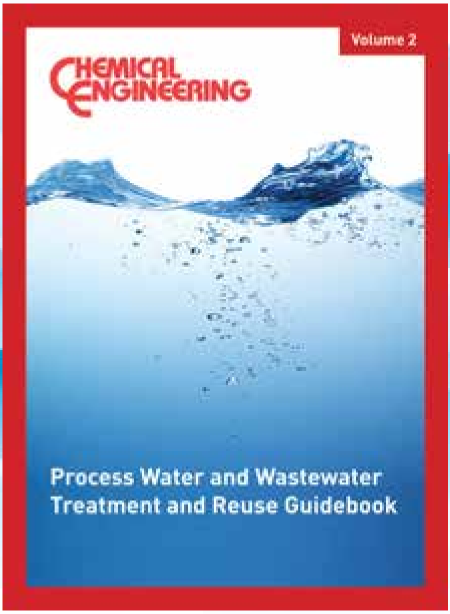

This guidebook contains how-to engineering articles formerly published in *Chemical Engineering*. The articles in Volume 2 provide practical engineering recommendations for process operators faced with the challenge of treating inlet water for process use, and treating industrial wastewater to make it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

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

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