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May 2015
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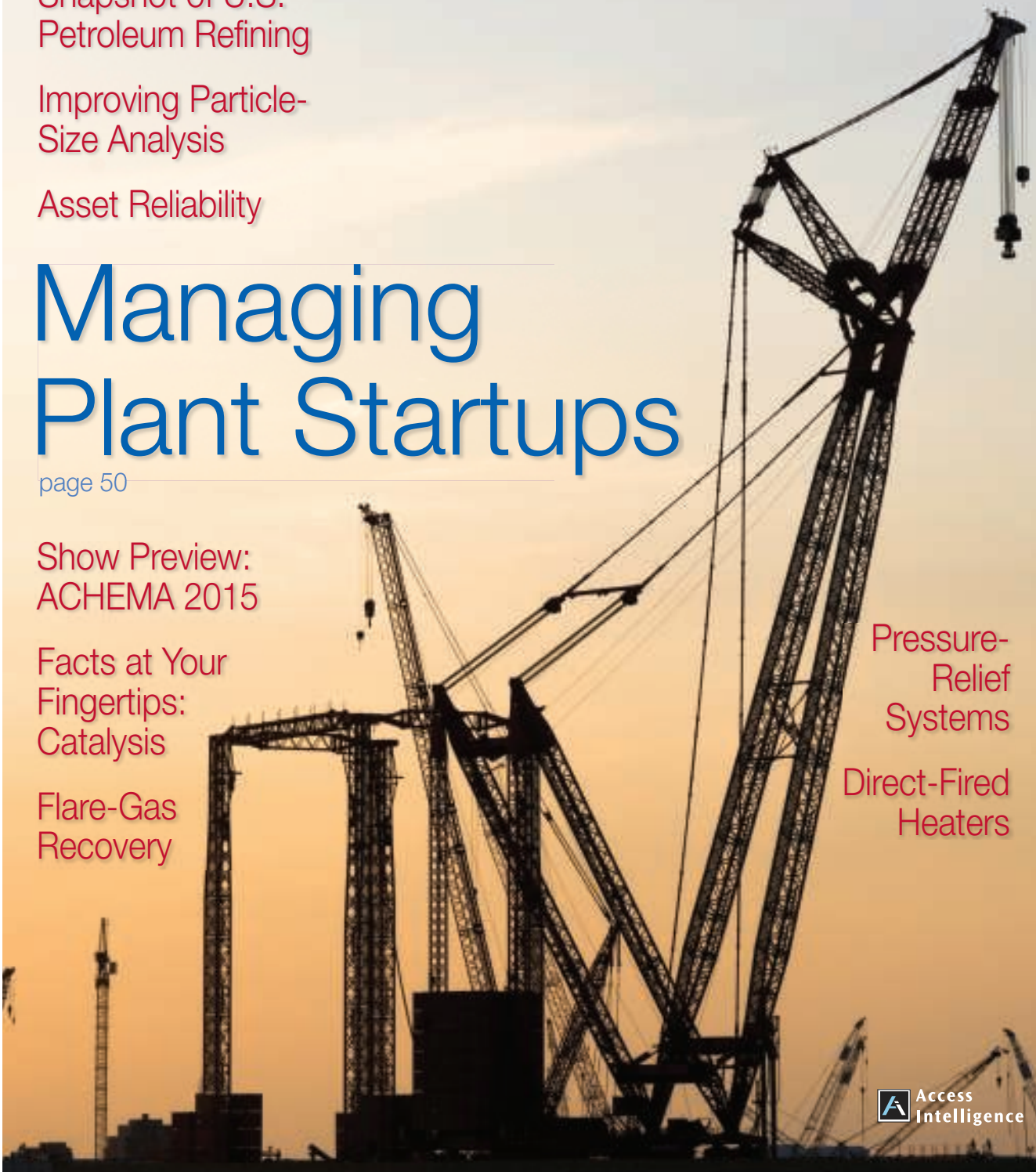

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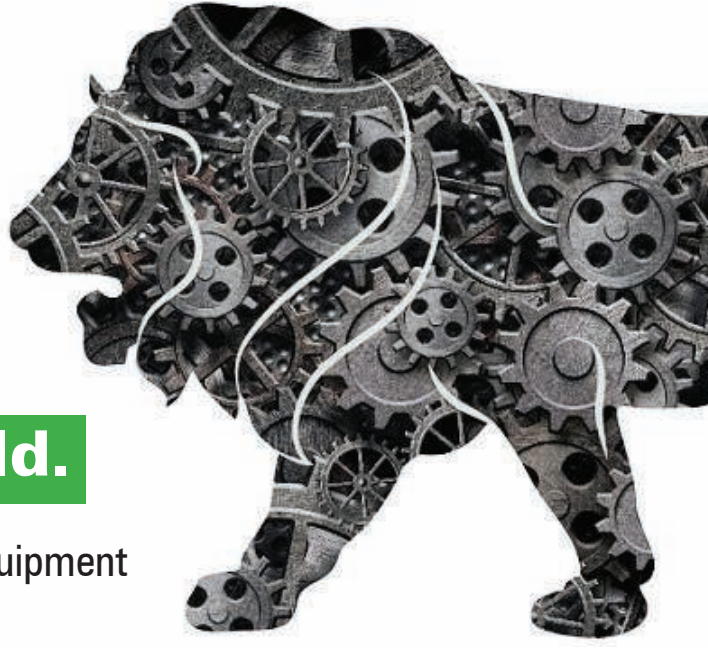

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ACHEMA 2015

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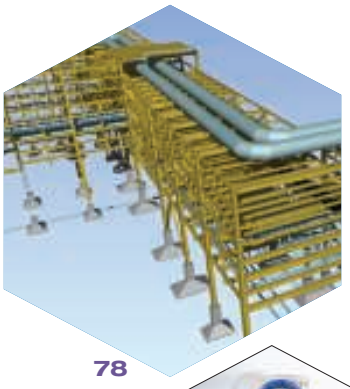
May 2015 Volume 122 | no. 5

Cover Story

In the News

Technical and Practical



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–2013 Pulse of the Profession, Project Management Institute

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A project is considered to have failed if the achedule slips or the project overspends by more than 25%, the execution time is 50% longer, or there are severe and continuing operational problems into the second year of the project.

–Speed Kills, Klaver, Ali. 2012 Project Manager Magazine

40 percent of projects in the oil and gas industry are subject to budget and schedule overruns.

–Capital Project Execution in the Oil and Gas Industry. M. McKenna, H. Wilczynski, D. VanderSchee. 2006 Booz Allen Hamilton survey from 2006 of 20 companies (super-majors, independents and EPC firms)

budget & schedule **OVERRUNS** **40%**

30% anticipated value **DISAPPEARS**

Up to 30 percent of anticipated value disappears during the turnover/ commissioning and ramp-up phases of new asset lifecycles.

–Deloitte. Effective Operational Readiness of Large Mining Capital Projects - Avoiding value leakage in the transition from project execution into operations. Article, 2012.

20% cost savings

39% schedule **REDUCTION**

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–Construction Industry Institute: Adding Value Through Front End Planning. CII Special Publication 268-3

PERSONNEL

50% expected to **RETIRE**

50% of experienced and managerial personnel in national and international oil gas processing companies are expected to retire in the coming decade.

–Society of Petroleum Engineers, "The Great Crew Change: A Challenge for Oil Company Profitability", April 16, 2011.

6 TO 7 YEARS

It takes an average of six to seven years to develop new employees into autonomous petrotechnical professionals who can make non-standard, original technical decisions.

–2010 SBC Oil & Gas HR Benchmark, Schlumberger Business Consulting Energy Institute, March 2011

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Editor's Page

Have you noticed?

If you've been noticing something different about your recent issues of *Chemical Engineering* — you are right. We have changed our look. With the February 2015 issue, we unveiled our newly redesigned print magazine. This May issue is our fourth, and biggest-to-date issue that sports our new look.

Changes to print

The most obvious change is probably our new logo, with its fresh, modern design. Our logo also incorporates a *CE* icon, which we use in the magazine to help quickly identify where readers can find more on a particular topic online at www.chemengonline.com. In addition to a new logo, changes to our printed magazine also include the following:

- Short "In Brief" summaries have been added to the beginning of articles, particularly our longer articles, to give a quick overview of what you can expect to find inside
- Our pages are now color-coordinated with the Table of Contents so that you can more easily flip to a section of interest
- We moved our Business News section to the news area of the magazine — a better fit. And, we've expanded the section and included a quick lineup of the companies that are mentioned for a quick reference
- Some changes to our print fonts and spacing were made to enhance readability. We kept this to a minimum, though, so that we can still pack a lot of information onto each page
- Our Who's Who, Bookshelf and Calendar sections have been moved online to our website, which was redesigned late last year. Our website is also where you'll find more latest news from the chemical process industries (CPI)

The bigger picture

We are very happy to be able to continue to bring you the same practical, relevant content that *Chemical Engineering* has been known for, for more than a century, in a new, modern format. At the same time, *CE* continues to grow to be much more than a magazine. Did you know, for example, that we have over 9,800 followers on Twitter, or that we have a LinkedIn group with close to 45,000 members? We have recently expanded our portfolio of e-newsletters, which you can sign up for on our website. And we are planning to offer more webinars on relevant topics again this year. If there is something specific that you would like to see, please let us know. The feedback we receive from our readers is very much appreciated, and it helps guide us to offer what you are looking for. So whether it is via our reader surveys or sending us an email, we look forward to your comments and suggestions, which help make us more valuable to you.

Inside this issue

This issue covers a host of topics, including practical planning and scheduling information to facilitate startup activities; a snapshot of the current state of the U.S. petroleum refining industry; articles on reliability, flare-gas recovery, direct-fired heaters, and pressure-relief systems; the first of our Achema Show Previews; the latest in technology news in our Chementator section; and much more. We hope you enjoy it. ■

Dorothy Lozowski, Editor in Chief

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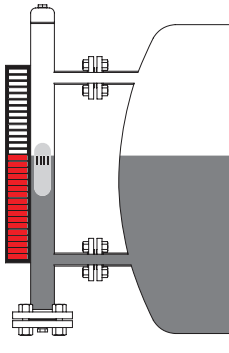
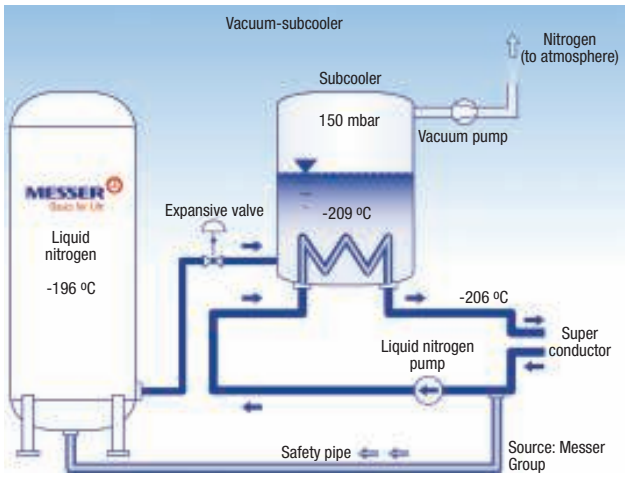


New cryogenic technology for cooling superconducting cables

Industrial gases specialist Messer Group GmbH (Bad Soden, Germany; www.messergroup.com) has developed a new cryogenic technology that makes it possible to use liquid nitrogen (LN_2) to cool high-temperature superconducting (HTS) cables down to –209°C, which is significantly lower than that normally achieved by LN_2 (–196°C). The new process was developed for the AmpaCity project of RWE Deutschland GmbH (Essen, Germany; www.rwe.com), in which a 1-km long, 10-kV superconductor cable replaced the conventional 110-kV lines between two substations in the city center of Essen, Germany. The HTS cable was developed by project partner, Nexans Deutschland GmbH (Hannover, Germany; www.nexans.com), and was commissioned in April 2014.



In Messer's process (diagram), N_2 is vaporized at about 150 mbar, which lowers the boiling point to –209°C, thus achieving the specification for the cables (N_2 freezes at –210°C, so lower temperatures are not possible). The LN_2 is pumped through the HTS cable in order to conduct away any heat that penetrates through the thermal insulation, explains Friedhelm Herzog, senior manager for industrial application at Messer. The N_2 heats up from –206°C when it enters the cable, to –201°C at the exit. The warmed LN_2 is then re-cooled in a specially engineered subcooler, which uses LN_2 at –209°C as cooling agent.

In order to ensure safety of the plant, we use the LN_2 supply tank for venting purposes as well, says Herzog, so that LN_2 can be flushed from the cable in the event of the cable suffering damage without it escaping uncontrolled into the environment. A patent application has been made for the routing system that is used for this purpose, he says.

Other applications involving very high electrical currents — for example, electrolysis plants — would benefit from this technology, because superconducting cables can transport five times the amount of electricity through cables with the same cross-section, and at a relatively low voltage, says Herzog.

Edited by:
Gerald Ondrey

A NATURAL FUNGICIDE

An international research team, led by Yoshikazu Ohya at the University of Tokyo (www.ib.k.u-tokyo.ac.jp), has discovered a new chemical compound that inhibits the growth of pathogenic fungi. The new compound, called poacic acid, was isolated from hydrolyzed lignocellulose and its antifungal properties were studied by Ohya's group, in collaboration with researchers from the University of Wisconsin-Madison, Riken (Yokohama, Japan) and the University of Minnesota.

Poacic acid was shown to be effective against several widespread fungal crop pathogens: *Sclerotinia sclerotiorum* (white mold in a wide range of plants), *Alternaria solani* (early blight in potatoes and tomatoes) and *Phytophthora sojae* (root and stem rot in soybeans).

BIOPROPANOL

The research group of professor Michihiko Kataoka at Osaka Prefecture University (Osaka, www.osakafu-u.ac.jp) has genetically engineered *E. coli* to produce 1-propanol by the fermentation of glucose. The

(Continues on p. 8)

A pulsation dampener that decreases pump energy consumption

A new pulsation dampener benefits from a design that can reportedly decrease energy usage. The Expulse, a flexible, inline pulsation dampener recently released by Flowrox Inc. (Linthicum, Md; www.flowrox.us), consists of a reinforced outer hose and an expansive inner hose, with compressed-air filler gas between the layers. Along with stabilizing flow and reducing noise, the Expulse can also decrease pump energy usage by 10%, according to the company. In cases of high discharge pressure, the energy created by flow stoppage and kickback is temporarily stored in the Expulse's inner hose and filler gas. Since some of the energy remains inside the dampener, flow kickback is decreased. In laboratory tests, the company observed a 15% increase in flow when using the dampener, meaning that with the dampener installed, desired flowrates could be achieved at a lower pump speed. Decreasing the pump speed while still achieving desired flowrates translates into around 10% energy savings for the pump. These energy savings, along with reduced vibrations and pulsations, lead to longer lifetimes for bearings and gearboxes.

With its inner hose constructed of a specially made elastomer, the Expulse's flexibility also sets it apart from steel-based dampeners, says the company, in that its flexible construction, in addition to providing for easier maintenance, allows it to absorb up to 90% of flow pulsations. With each pulse, the diameter of the flexible inner hose expands, which prevents slurry sedimentation within the hose and acts as a self-cleaning mechanism, further increasing efficiency.

Note: For more information, circle the 56-digit number on p. 102, or use the website designation.

1-propanol yield from the engineered strain has been shown to be 1.5 to 2 times higher than that achieved by others, says Kataoka. The higher yield was achieved by suppressing the production of CO_2. Kataoka believes the technology is a first step toward a sustainable route for making biopropylene, a precursor for polypropylene.

SORTING BIOMOLECULES

Researchers at Harvard University (Cambridge, Mass.; www.harvard.edu) have demonstrated a hybrid chemical-mechanical system that can be used for the detection and separation of biomolecules. The system consists of an array of microscopic polymeric fins with attached nucleic acid molecules, which can recognize specific target molecules. The polymer fins are embedded in a hydrogel that undergoes volume changes in

(Continues on p. 14)

Air-capture of CO_2 using waste process heat

Carbon-negative technology being commercialized by Global Thermostat LLC (New York, N.Y.; www.globalthermostat.com) removes carbon dioxide directly from the atmosphere using low-cost waste process heat from industrial processes. The technology works in a similar fashion to cogeneration approaches and could transform heavy CO_2-emitters into carbon sinks, according to the company.

Founded by Graciela Chichilnisky and Peter Eisenberger — Columbia University (New York, N.Y.; www.columbia.edu) professors who are contributors to the Intergovernmental Panel on Climate Change (IPCC; Geneva, Switzerland; www.ipcc.ch) — Global Thermostat built a demonstration facility for the technology at the Silicon Valley campus of research nonprofit SRI International (Menlo Park, Calif.; www.sri.com). The company recently secured a commercial partnership with NRG Energy.

The technology works by blowing air (or an air/fluegas mixture) over a wall of honeycomb contactors developed by Corning Inc. (Corning, N.Y.; www.corning.com). Similar to the high-surface-area materials used in automobile catalytic converters, the Corning monoliths allow contact with large volumes of air at small pressure drops and low cost. The honeycomb monoliths are coated with a proprietary solid amine-based sorbent material developed by BASF SE (Ludwigshafen, Germany; www.basf.com).

The solid sorbent material occupies pores in the contactor material and captures CO_2 molecules flowing through the device. The solid sorbent releases CO_2 at much lower temperatures compared to those for liquid-based carbon capture. CO_2 is released using low-temperature (~85–90°C) residual process heat and water vapor, and the sorbent is regenerated. The CO_2 is stored for use in commercial applications.

The vast resources (~$55 trillion, according to the International Energy Agency; Paris; www.iea.org) invested in fossil-fuel-based energy infrastructure and the long-term persistence of CO_2 in the atmosphere make carbon-reduction technologies critical to climate-change policies, explains Global Thermostat CEO Chichilnisky, the author of the carbon market provisions of the Kyoto Protocol. “We need inexpensive carbon-removal technology that will not be a drag on economies,” she says.

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Construction to begin on biomass-to-fuels facility

Construction is set to begin on a biorefinery in Oregon this summer that will manufacture bio-based jet fuel and diesel from forest and sawmill residues. When it begins producing biofuels at the end of 2016, it will be capable of converting 140,000 dry tons of wood waste into 15 million gal of fuel annually, according to Terry Kulesa, the co-founder and president of Red Rock Biofuels (Fort Collins, Colo.; www.redrockbio.com), the company that will operate the facility.

Red Rock has engineered a process (photos) that combines existing technology in a novel manner to make jet fuel, diesel and naphtha from wood chips and small limbs leftover from sawmills. The process relies on a gasifier that integrates gasification with systems for steam-methane reforming (SMR) water-cleaning. The clean synthesis gas generated by the gasifier is fed to a Fischer-Tropsch (F-T) microchannel reactor from Velocys (Plain City, Ohio; www.velocys.com; see *Chem. Eng.*, January 2010, pp. 17–19). The product mix from the small-scale F-T reactor is then refined to yield a 40/40/20% mix of jet fuel, diesel and naphtha, respectively.

"Commercialization depended on de-risking the process," Kulesa says, "by utilizing established technology in a unique way." Other keys include access to a fixed-price feedstock and the willingness of end-users to enter into long-term offtake agreements.

During its process development, Red Rock received two grants from the U.S. Depts. of Agriculture, Energy and Navy, and Kulesa says the company has recently negotiated offtake agreements with Southwest Airlines and another major jet fuel consumer that will be announced soon.

An effective graphene-based desalination membrane

Researchers from Oak Ridge National Laboratory (ORNL; Oak Ridge, Tenn.; www.ornl.gov) have demonstrated an efficient desalination process using a porous graphene-based membrane. While the thinness of the freestanding graphene (roughly 0.3 nm) allows for significantly higher flux than traditional reverse-osmosis processes, the major breakthrough in the membrane's efficiency came with targeting the optimal pore configuration. The size and spacing of the pores is key, and the team applied atom-resolution imaging to optimize these parameters for desalination purposes. The resulting pore size, 0.5–1.0 nm, was found to be large enough for water molecules to pass through, while remaining small enough to prevent salt ions from penetrating.

To create the pores, the graphene layer, which resides on a silicon nitride skeleton, was exposed to

a highly reactive oxygen plasma that etches away at the graphene's carbon atoms, until holes are formed in the layer. The pores themselves are punctuated with silicon atoms — not oxygen or carbon — a noteworthy phenomenon that the researchers attribute to the silicon's potential stabilizing effect on the pores. The size of the pores depends on the amount of time that the membrane is exposed to the oxygen plasma.

Controlling pore size is among the most challenging tasks in scaling up this technology beyond the currently demonstrated milliliter scale. As the membrane surface area gets larger, there will be added difficulty in maintaining the optimal pore density of one pore per 100 nm^2. Ensuring mechanical stability (while remaining at the desired pore density) as the membranes get larger will also be key to moving to pilot and commercial levels. In addition to the oxygen-plasma approach, the team is also researching alternative, more controllable methods of pore production to help alleviate some of these concerns.

Making bioethanol directly from starch

Today, the cost of enzymes continues to make bioethanol uncompetitive as a fuel. Eliminating the need for amylases, which are used to hydrolyze starch into fermentable sugars, would be a key step toward reducing the operating costs for producing bioethanol. Such a breakthrough has now been achieved, by reachers from Japan, led by Jyun Shima at Ryukoku University (Otsu; www.ryukoku.ac.jp) and Ayumi Tanimura at Kyoto University (Kyoto, both Japan; www.kyoto-u.ac.jp). The scientists have isolated a yeast strain that directly produces ethanol from starch.

The researchers use a technique called consolidated bioprocessing (CBP), which integrates enzyme production, saccharification and fermentation in a single reactor using a single yeast strain. Their CBP process is said to be superior to alternative methods that use genetically modified organisms (GMOs), which require a complex production process to ensure physical containment of the GMOs.

In this study, the researchers performed comprehensive screening to find natural isolates of yeast that could produce ethanol without having to add amylases. Of the 530 yeast strains tested, three strains were found to produce more than 6 g/L of ethanol. After 10 d of cultivation, ethanol production by *S. shehatae* JCM 18690 reached 9.2 g/L. It was verified that the increase in the ethanol concentration of *S. shehatae* JCM 18690 was mainly due to the increase in its gluco-amylase activity.

The new yeast strain was also shown to be ethanol-tolerant, with the ability to ferment xylose contained in biomass at temperatures higher than the normal 20–30°C range. The achievement has the potential to enable ethanol production from inexpensive and abundant renewable carbon resources, such as cassava pulp and food wastes.

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Nanolaminated alloys 'grow' parts for enhanced corrosion resistance

By controlling material interfaces at the nano-scale, Modumetal Inc. (Seattle, Wash.; www.modumetal.com) has developed a method for creating a new class of alloys with precisely defined properties through nanolamination. In this process, a part, such as a valve or fastener, is submerged in a tank containing various metal electrolytes. Through current-controlled electric-field modulation, metal ions are deposited onto the part in specific microstructures and layers. Unlike other electric-field-modulation processes, which are based on mass-transfer control, this process modulates the composition and structure of the alloy continuously. This level of control over the alloy's properties at the interface between the original part and the deposited layer allows for customized parts to be "grown" — a process the company likens to biological activities, such as the growth of tree trunks.

Modumetal

The company touts corrosion resistance among the most desirable benefits of nanolamination. In partnership with various oil-and-gas companies, Modumetal has performed numerous demonstrations of specialized nanolaminated parts (including large-scale equipment, such as pumps and valves) in downhole and marine environments. In recently published field-test results, the zinc-based nanolaminated coatings showed unprecedented corrosion resistance when compared with traditional materials, including galvanized parts and those with cadmium-based coatings, all while maintaining strength and thickness requirements.

Last year, the company opened a full-scale production facility for its nanolaminated coatings in Snohomish County, Wash. Here, equipment and tubular components of many types are nanolaminated. Because the metals are grown using low-cost electrochemistry, Modumetal says the nanolamination process can operate with economics similar to traditional electroplating processes, even for large length scales of 12–20 ft. Additionally, smaller components like fasteners are processed with very high throughput. Modumetal currently works with both end-users and equipment manufacturers to clad the materials. Going forward, Modumetal will continue working alongside industry leaders to deploy its nanolaminated coatings.

response to chemical stimuli (in this case, pH changes). The Harvard team immersed the hybrid assembly in a two-phase microfluidics system with top and bottom fluid layers in laminar flow. The polymeric fins were able to capture the protein thrombin in the top layer because they were adorned with the specific polypeptide sequence for the target biomolecule. Then the team was able to move the captured thrombin molecules to the bottom fluid layer with a shift in pH. The assembly could inspire hybrid assemblies for low-energy separation and purification.

NANO-COATING

Coatings that change color depending on the temperature have been developed by researchers at the Fraunhofer Institute for Chemical Technology (ICT; Pfinztal, Germany; www.), in collaboration with industrial partners

(Continues on p. 16)

A desalination membrane that is resistant to chlorine

The major drawback of existing membranes for desalination plants is that the membranes are not tolerant of oxidizing agents, such as chlorine. To overcome this drawback, a team of researchers from the University of Melbourne (www.unimelb.edu.au) and CSIRO (Melbourne, Australia; www.csiro.au), led by professors Sandra Kentish and Frank Caruso, has developed a chlorine-resistant desalination membrane.

The membranes are produced by the assembly of dense polyelectrolyte multilayer (PEM) membranes, which are crosslinked via imine bonds. The layer-by-layer assembly of the polyelectrolytes, polystyrene sulfonate (PSS) and poly(allylamine) hydrochloride (PAH), facilitated the rapid formation of a selective membrane layer with precise control over the membrane's thickness and composition. Interlayer crosslinking of PAH was induced via immersion in glutaraldehyde (GA) solution, facilitating imine bond formation. The team studied the membranes' performance in the separation of Na^+ and Cl^- ions from brackish water (2,000 ppm concentrations).

According to the team, the interlayer crosslinking created a tighter membrane pore size and reduced membrane swelling. As a result, ten deposition cycles of PSS/PAH were adequate to form a selective membrane layer with NaCl rejection of more than 95%, the team says. Since only the polycationic layer participates in the crosslinking reaction, the PSS polyanion can then be substituted with another anionic polymer. To this end, a highly sulfonated polysulfone was synthesized and, according to the team for the first time, deposited from an aqueous solvent to create a sPSf/PAG PEM assembly. The resultant membrane exhibited similar NaCl rejection to PSS/PAH membranes, but showed much greater resistance to chlorine.

The team said the results suggest that PEM membranes have outstanding potential for reverse osmosis applications where chlorine resistance is desired. The team is seeking a commercial partner to fund further development of the membrane material.

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under a project funded by the German Federal Ministry of Education and Research (BMBF; Bonn, Germany). These so-called thermochromic nano-coatings are black if the temperature is below 30°C, and thus become heat absorbers. When the temperature rises, the color changes and the coating becomes transparent, thereby allowing infrared (IR) radiation to be reflected. The nano-coatings can be applied to metal strips or wires, which can then be interwoven and used as exterior, self-regulating thermal cladding for walls and facades to help cool buildings passively and thereby reduce utility costs.

ICT developed a process that evenly distributes nano-particles into a polymer matrix. The coatings can be applied directly to a metal, without the need for a primer coat. The coating also prevents O_2 from reaching the metal, thus preventing corrosion.

GM eucalyptus yields more wood

Last month, the Brazilian National Technical Commission on Biosafety (CTNBio) approved the commercial use of the yield-enhanced eucalyptus tree developed by FuturaGene (www.futuragene.com), a wholly owned subsidiary of Suzano Pulp and Paper (São Paulo, Brazil; www.suzano.com.br). Field experiments conducted since 2006 at various locations in Brazil have demonstrated an approximate 20% increase in yield compared to its equivalent conventional variety.

This is the first genetically modified (GM) eucalyptus event to be approved worldwide and represents the most significant productivity milestone for the renewable plantation forest industry since the adoption of clonal technology in the early 1990s, says FuturaGene. This approval also represents the beginning of a new era for sustainable forest management by enabling the production of more fiber, using less resources. Brazil is the first country to complete the development cycle of such a technology.

FuturaGene's yield-enhanced eucalyptus has been under development since 2001 and has undergone extensive biosafety assessment prior to submission for commercial approval.

'Up-cycling' perfluorinated polymers

At the end of March, Dyneon GmbH (Burgkirchen, Germany) — a fully owned subsidiary of 3M Co. (www.3m.com) — together with its cooperating partners, the Deutsche Bundesstiftung Umwelt, the University of Bayreuth and the institute InVerTec, opened the world's first fluoropolymer "up-cycling" facility in Burgkirchen, Germany. The new pilot plant can up-cycle up to 500 ton/yr of fluoropolymer waste.

The new pilot plant integrates seamlessly onsite into Dyneon's existing fluoropolymer-production lines, and employs pyrolysis to decompose perfluorinated polymers, recovering gaseous monomers, which are cleaned prior to feeding them back into the manufacturing process for new materials. The plant will process fully fluorinated polymers, such as PTFE, PFA and FEP, but a second phase will target polymer compounds containing fillers.

The project was funded with a €1 million grant from the German Federal Ministry for the Environment (BMU; Berlin).

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Plant Watch

Roquette launches isosorbide production unit in France

April 10, 2015 — Roquette Freres (Lestrem, France; www.roquette.com) has started operations at a new unit for the production of isosorbide at its site in Lestrem. The new unit will produce 20,000 metric tons per year (m.t./yr) of isosorbide.

Shin-Etsu to establish production base for photoresist polymers in Taiwan

April 10, 2015 — Shin-Etsu Chemical Co. (Tokyo, Japan; www.shinetsu.co.jp) will build a new plant in Taiwan that will produce photoresist polymer materials, which are used in the manufacture of semiconductor devices. The construction of the plant is expected to be complete in about a year.

Lanxess starts up EPDM rubber plant in China

April 9, 2015 — Lanxess AG (Cologne, Germany; www.lanxess.com) has started up a new production plant for ethylene propylene diene monomer (EPDM) rubber in Changzhou, China. The plant has a nameplate capacity of 160,000 m.t./yr, producing ten premium grades of EPDM.

A. Schulman to establish masterbatches plant in Turkey

April 8, 2015 — A. Schulman, Inc. (Akron, Ohio; www.aschulman.com) plans to invest around €5–7 million in establishing a new masterbatch production plant in Turkey. This new facility will produce approximately 18,000 m.t./yr of masterbatches for food and industrial packaging, and is expected to start up by the end of 2016.

Tecnimont awarded contract for Socar polypropylene plant

April 7, 2015 — Maire Tecnimont S.p.A. (Milan, Italy; www.mairetecnimont.com) reached an agreement with the State Oil Company of Azerbaijan Republic (Socar) for a contract for a new polypropylene plant. The total contract value is approximately €350 million. The plant will have a capacity of about 180,000 m.t./yr of polypropylene.

Sipchem starts up manufacturing facility for EVA and LDPE

April 1, 2015 — Saudi International Petrochemical Co. (Sipchem; Al Khobar, Saudi Arabia; www.sipchem.com) began commercial operations at a new plant that will produce ethylene vinyl acetate (EVA) and low-density polyethylene (LDPE). The plant's capacity will be 200,000 m.t./yr of EVA and LDPE.

AkzoNobel to invest in organic peroxide operations in the U.S. and Europe

March 26, 2015 — AkzoNobel (Amsterdam, the Netherlands; www.akzonobel.com) plans to invest more than €20 million in its organic peroxide production facilities in Mons, Belgium and Pasadena, Tex. In Pasadena, a newly implemented site-wide process-control system is expected to significantly improve capacity.

Asahi Glass raising PVC production capacity in Vietnam

March 25, 2015 — Asahi Glass Co. (AGC; Tokyo; www.agc.com) plans to increase the production capacity at the polyvinyl chloride (PVC) facility of Phu My Plastics & Chemicals Co. (PMPC), AGC's subsidiary in Vietnam. PMPC's PVC production capacity will be increased by 50% to 150,000 m.t./yr. Expanded operations are scheduled to commence at the beginning of 2016.

LyondellBasell to expand tri-ethylene glycol capacity in Texas

March 24, 2015 — LyondellBasell (Rotterdam, the Netherlands; www.lyondellbasell.com) plans to expand production capacity for tri-ethylene glycol at the company's existing plant in Pasadena, Tex. The additional capacity of around 23,000 m.t./yr will more than double the company's current production capacity. The new unit is anticipated to be operational in late 2016.

Fluor awarded engineering contract for new Chinese polysilicon plant

March 24, 2015 — Fluor Corp. (Irving, Tex.; www.fluor.com) was awarded a contract by Shaanxi Non-Ferrous Tian Hong REC Silicon Materials Co. for a new polysilicon plant located in Yulin, China. The plant will have a total investment of over $1 billion.

PPG completes resin-production plant in Brazil

March 19, 2015 — PPG Industries, Inc. (Pittsburgh, Pa.; www.ppg.com) announced the completion of a $40-million, 65,000-ft^2 plant for onsite resin production at its Sumaré, São Paulo, Brazil, coatings manufacturing facility.

Mergers & Acquisitions

Kuraray acquires bio-based film specialist Plantic

April 10, 2015 — Kuraray Co. (Tokyo, Japan; www.kuraray.co.jp/en) has acquired Plantic, an Australia-based producer of bio-based barrier materials. The acquisition enables Kuraray to provide barrier materials for bio-based food-packaging products.

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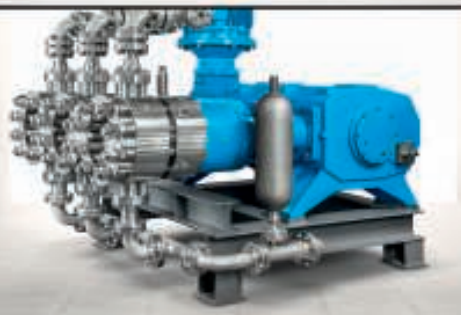

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Creating Fluid Solutions

Sinopec and EMRE to develop fluidized-bed MTG technology

April 1, 2015 — Sinopec Engineering (Group) Co. (Beijing, China; www.sinopecgroup.com) and ExxonMobil Research and Engineering Co. (EMRE) are participating in a cooperative development agreement for the advancement of fluidized-bed methanol-to-gasoline (MTG) technology with the intent to globally license the technology.

Haldor Topsøe and Ferrostaal to form joint venture

April 1, 2015 — Ferrostaal GmbH (Essen, Germany; www.ferrostaal.com) and Haldor Topsøe A/S (Lyngby, Denmark; www.topsoe.com) have established Ferrostaal Topsøe Projects GmbH, a new joint venture (JV) that will be based in Essen and equally owned by the two companies. The JV will focus on developing, financing and realizing major industrial projects.

ThyssenKrupp Uhde Chlorine Engineers JV starts operations

April 1, 2015 — The JV between ThyssenKrupp Industrial Solutions AG (Dortmund, Germany; www.thyssenkrupp-industrial-solutions.com) and electrochemical technologies supplier De Nora S.p.A. (Milan, Italy; www.denora.com) began operations, trading under the name ThyssenKrupp Uhde Chlorine Engineers.

Olin to merge with Dow chlorine business

March 27, 2015 — The Dow Chemical Company (Dow; Midland, Mich.; www.dow.com) will separate a significant portion of its chlorine value chain and merge that new entity with Olin Corp. (Clayton, Mo.; www.olin.com) in a transaction that will create a new company with revenues approaching $7 billion. The transaction is expected to close by year-end 2015.

Cepsa's Canadian PTA business acquired by Indorama

March 23, 2015 — Indorama Ventures Public Co. (IVL; Bangkok, Thailand; www.indorama.net) has signed an agreement to acquire 100% of the Montreal-based purified terephthalic acid (PTA) business of Cepsa Química SA. Cepsa's plant is the only PTA facility in Canada, and has a capacity of approximately 600,000 m.t./yr of PTA.

A. Schulman acquires Citadel Plastics for $800 million

March 18, 2015 — A. Schulman, Inc. has acquired privately held Citadel Plastics Holdings, Inc. (West Chicago, Ill.) for $800 million. Citadel produces thermoset composites and thermoplastic compounds for specialty product applications.

Indorama acquires PET producer in Thailand

March 18, 2015 — A subsidiary of Indorama Ventures Public Co. has signed a definitive share-purchase agreement with Bangkok Cable Co., to acquire a 94.91% equity stake in Bangkok Polyester Public Co. (BPC). BPC is a producer of polyethylene terephthalate (PET) polymers with a capacity of 105,000 m.t./yr. ■

Mary Page Bailey

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U.S. Petroleum Refining: Snapshot 2015

Developments from the 2015 AFPM annual meeting frame a picture of the current state of the U.S. petroleum refining industry

IN BRIEF

On a broad level, the outlook for the U.S. petroleum-refining industry remains bright, despite a recent decline in crude oil prices. Dramatic gains in the production of crude oil and natural gas in North America have given U.S. refiners access to low-cost energy and discounted feedstocks. Meanwhile, investments in capital and technology are positioning them to take advantage of the diverse and dynamic crude-oil slate available. But while the elements are in place for a prospering industry, success and profitability do not come easily, and petroleum refiners each must navigate a unique path that is beset by technical, regulatory and logistical challenges.

The annual meeting of the American Fuel and Petrochemical Manufacturers (AFPM; Washington, D.C.; www.afpm.org), held in late March in San Antonio, Tex., provides a forum for assessing the state of the petroleum-refining industry in the U.S. and for discussing some of the many challenges facing the sector.

Solid margins

Exploitation of shale deposits in the U.S. has meant that the country has experienced continued low natural-gas prices — which keep energy and utility prices down for industry — along with increased availability of domestic crude oil that is priced at a discount compared to international crudes. The two related developments combined to support the generally high margins enjoyed by U.S. refineries over the past few years. And despite the dip in crude oil prices overall, margins are expected to remain relatively strong over the next several years.

Going forward, refinery margins are forecast to be supported also by robust export markets for U.S.-made gasoline and petroleum distillates, according to oil-and-gas consultancy Wood Mackenzie (Edinburgh, U.K.; www.woodmac.com). Analyses from Wood Mackenzie suggest that while crude oil discounts in the U.S. will decline somewhat as the capacity for takeaway in U.S. oil plays increases, U.S. refining margins are expected to remain strong.

In presentations at the AFPM meeting, Wood Mackenzie's Alan Gelder and Sam Davis pointed out that despite the increased takeaway capacity, "the opportunity still exists to displace foreign crudes through feedstock optimization and logistics projects to enhance refinery profitability."

"Most U.S. refiners are working with a dynamic feedstock slate, and they need flexibility to take advantage of short-term changes in feedstock prices, availability and product demand," comments Rosann Schiller, marketing director for fluid-catalytic-cracking (FCC) catalyst products at W. R. Grace & Co. (Columbia, Md.; www.grace.com).

Tight oil capacity

U.S. domestic crude oil production has grown from approximately 1.9 billion bbl/yr in 2005 to almost 3.9 billion bbl/yr (average of 9.3 million bbl/d) in 2014. The Energy Information Administration (Washington, D.C.; www.eia.gov) forecasts that petroleum production in the lower 48 U.S. states will increase by 720,000 bbl/d by 2016. Most of the crude oil that accounts for the increase can be characterized as "tight oil" from shale formations. So-called light, tight oils (LTO) have high API gravities, a measure of oil density. High (>40) API gravity corresponds to low density crude oil. LTO are generally characterized by low sulfur and high paraffinic content and may have elevated concentrations of metals such as nickel, vanadium and iron (see *Chem.*

PETROLEUM REFINING POLICY AND REGULATORY ISSUES

The AFPM annual meeting also provides a chance to assess the status of various policy and regulatory issues that apply to the petroleum refining industry. Included here is a sampling of topics discussed during the meeting.

Cybersecurity: Keynote speaker General Michael Hayden, former director of the Central Intelligence Agency and the National Security Agency, discussed cyber-related threats to the petroleum refining and petrochemical industries during his talk on global sources of instability. Arguing that the nature of power has changed, Hayden said that power has shifted away from nation-states and toward "sub-state actors" and individuals. Perpetrators of cyberattacks are likely to fall into one of three groups: nation states (who are mainly looking to steal intellectual property rather than destroy assets); organized crime gangs (who are looking for money); and what he called "disaffected individuals" (who usually operate anonymously and who may have complex and difficult-to-determine motivations and objectives).

Crude by rail: The burgeoning production of oil from shale deposits has meant a tremendous increase in the volume of oil transported by rail — estimated by AFPM to be a 4,000% increase since 2008. Controversy surrounding the safety of rail cars used to transport the crude oil has not been far behind. AFPM president Drevna said that while U.S. refiners are investing in rail safety, the emphasis should be placed on preventing derailments, rather than on regulating the safety of the railcars.

Low-carbon fuel standards: AFPM joined two other organizations in filing a lawsuit against a low-carbon fuel standard proposal in Oregon. AFPM argues that the initiative, which it says is designed to promote an in-state biofuels industry, is unconstitutional because it discriminates against out-of-state manufacturers of transportation fuels. AFPM says the program "will cost consumers a lot of money," and is skeptical of the resulting environmental benefits.

Renewable fuel standard: AFPM renewed its harsh criticism of the Renewable Fuel Standard (RFS), mandates that certain volumes of renewable fuels be blended into gasoline and diesel fuels. AFPM opposes any mandates for the use of alternative fuels, and argues that the RFS should repealed or reformed.

Workforce initiative: The AFPM is also part of a workforce initiative designed to attract more students into STEM fields. Along with EdVenture Partners, AFPM is launching a nationwide industry-education partnership program to encourage students to pursue careers in the fuel-manufacturing and petrochemicals sectors.

New AFPM president: AFPM announced that its board of directors named Chet Thompson as the association's next president, to succeed Drevna starting in May 2015. Thompson has represented AFPM as external legal counsel for nine years at the law firm Crowell and Moring LLP.

Eng. May 2014, pp.17–20).

Since the rapid uptick in the production of light, tight oils, there has been a lingering concern that U.S. petroleum refiners lacked sufficient capacity to process the volume of LTO that has been observed and projected. This idea is a misconception, according to outgoing AFPM president Charlie Drevna, and is not the case. His assertion is supported by two surveys of U.S. petroleum refiners discussed at the AFPM meeting. The first, conducted on behalf of AFPM by a third-party group, indicates that the respondents posess enough processing capability to absorb all of the light oil production that is forecast. "The survey results . . . emphasize that U.S. refiners are not capacity-constrained in the next several years to use the growing super light production from U.S. tight oil formations," AFPM says.

A separate study, conducted by the consulting firm Baker & O'Brien Inc. (Dallas, Tex.; www.bakerobrien.com), came to a similar conclusion. Their study concluded that the U.S. refining fleet could technically process all available domestic crude with a combination of four strategies: 1) Increase processing through higher unit utilizations; 2) Substitute LTO for existing feedstocks; 3) Blend LTO with imported medium or heavy grades of crude oil; and 4) Make modest investments in the ability to process light crude oils. The study assumed that the economics of processing LTO remain positive, as forecast, and that delivery logistics would not present major problems.

In fact, many refiners have already started to adopt these strategies: the Baker & O'Brien study found that refinery throughput in the U.S. has increased by 2.5–3.0 million bbl/d and processing of imported crude oils has decreased by 1.0–1.5 million bbl/d. Further, refiners have announced expansions of distillation capacity for light-ends processing. Because of the current and projected discounted prices for LTO, the study suggests that refiners will likely continue to increase LTO processing and make opportunistic investments to overcome constraints in their ability to process light ends.

Analyses by Wood MacKenzie seem to agree, concluding that refinery investments in the U.S. have moved largely away from large expansions and traditional conversion-unit projects, and are "now targeted toward expanding distillation capacity to process additional light, 'sweet' crudes." These include domestic LTOs.

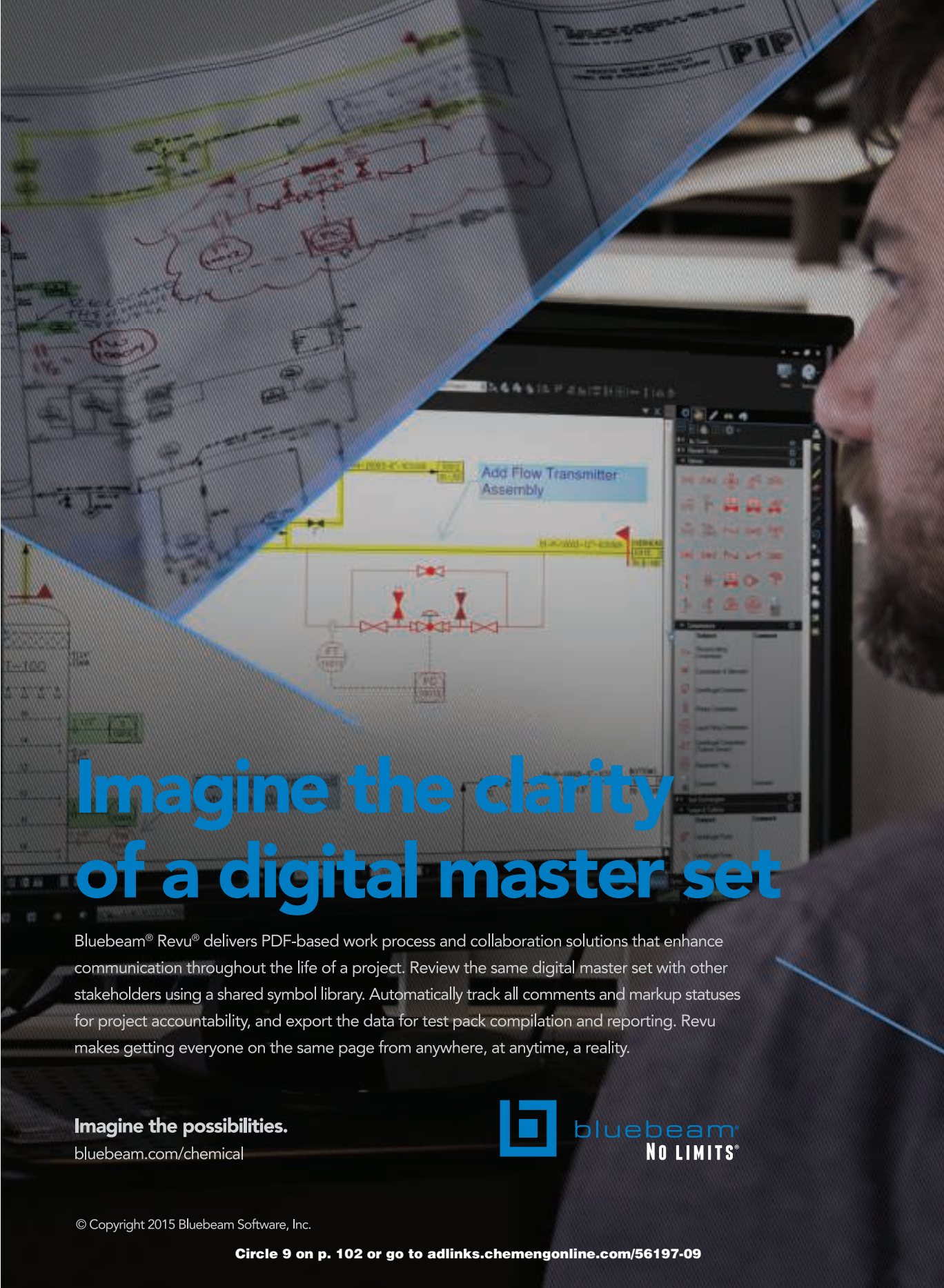
Shifting FCC products

But just because U.S. refiners are capable of handling higher LTO volumes doesn't mean clear sailing — hurdles exist. Crafting a successful refining strategy depends in large part on adapting a given refinery configuration to a variable and ever-changing feedstock slate. Process technology developers and catalyst manufacturing firms aim to enable the flexibility to mold that strategy.

Demand for gasoline, the traditional target for FCC units, has been declining in the U.S. and other developed areas due to a more fuel-efficient vehicle fleet. So refiners are looking for other ways to maximize the products from their FCC units. Among the general strategies is to better integrate refining activities with petrochemical production. An example of this is maximizing propylene production from the FCC unit.

Among the indirect effects of the shale gas revolution has been that ethylene crackers have shifted away from using naphtha as feedstock in favor of less expensive ethane, resulting in lower production of propylene and butadiene (see *Chem. Eng.*, Oct. 2012, pp. 17–19). The reduced propylene supplies, along with solid and growing demand, gives rise to an opportunity for petroleum refiners to adopt strategies that result in higher propylene yields. A number of talks at AFPM mentioned this dynamic.

Refiners can increase propylene



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recovery in FCC units through operational modifications (such as running at higher reactor temperature and higher catalyst circulation) and by increasing use of ZSM-5 additives to crack gasoline-range olefins into liquefied petroleum gas (LPG)-range olefins. ZSM-5 is a widely used aluminosilicate zeolite patented by Mobil in the 1970s. Presenters at the AFPM meeting, such as Bart de Graaf, from Johnson Matthey (London, U.K.; www.matthey.com), highlighted new knowledge that should allow an even more tailored approach for ZSM-5 additives in FCC catalysis.

"ZSM-5 does more than only cracking gasoline olefins into gasoline," de Graaf explains. "These effects become obvious when using 10% (or more) ZSM-5 additive in catalyst inventory."

At high ZSM-5 levels, gasoline- and LPG-range olefins are not only terminal products, but are also reactive intermediates that can undergo isomerization, cyclization, cracking and other reactions, de Graaf says. These can help refiners increase production of propylene and butylenes, improve gasoline octanes and also contribute to the formation of other petrochemicals, such as xylenes.

ZSM-5 has been shown to be indispensable in petrochemical FCC application, due to a combination of activity and selectivity, and also price. "When ZSM-5 was first applied more than 30 years ago, only a small fraction of the active zeolites in the FCC catalytic system was ZSM-5," explains de Graaf. "Now there are applications where there is nearly as much ZSM-5 crystal in inventory as faujasite [the normal zeolite used in FCC catalysts]."

Another example of refinery-petrochemical integration is the production of aromatic compounds, a group of chemicals for which demand is still growing. Aromatics such as benzene, toluene and xylenes (BTX) can offer value for FCC operators that wish to run at higher severity. At the AFPM meeting, GTC Technologies (Houston; www.gtctech.com) discussed technologies that can help separate these components from refinery streams, an endeavor that is difficult because of close boiling points and the existence of azeotropes.

In 2008, GTC introduced GT-BTX, an extractive distillation process that recovers and purifies aromatics from refinery streams. This was followed in 2013 by a related process called BTX-PluS, which removes BTX and thiophenic sulfur species from cracked naphtha. Originally designed as a sulfur-removal technology, BTX-PluS is also effective at directly recovering aromatics from FCC-derived gasoline for use in petrochemicals applications. This topic was the subject of a presentation at the AFPM meeting. The company points out that the novel technology can effectively remove sulfur and aromatics from gasoline, without hydrotreating the full stream, which can lower octane values.

"In conventional hydrodesulfurization units, you see hydrogenation of olefins, which lowers octane numbers in the product," explains David Bridgeman, GTC Technologies global licensing and business development manager. "We paired an extractive distillation technique with a specially developed solvent to allow lower sulfur levels without loss of octane values," he says. Simultaneously, the process can isolate high-value BTX products for further processing at lower energy cost and lower capital expense than traditional approaches.

Octane boost

Overall, production of diesel fuel as a refinery product has been growing faster than gasoline, as domestic demand for gasoline has been flat, but globally, gasoline demand is still growing, driven by emerging economies. And requirements for gasoline quality are growing. The use of petroleum alkylate as a gasoline blendstock supports the higher quality, because of its high octane value, low vapor pressure, absence of aromatics and low sulfur content.

Several talks at AFPM discussed

AFPM 2015 CONFERENCE NOTES

The AFPM annual meeting featured nine conference tracks over two days, covering a wide range of topics from technical issues to process safety. The following represents a small sample of the presentations from the event.

Wastewater treatment: Tina Syvret and Sam Lordo, from Nalco Champion (Houston; www.nalcochampion.com), made the argument that the same focus on making refinery modifications for processing light, tight oils and oil sands should also be brought to wastewater treatment systems. Their presentation outlined strategies related to wastewater treatment that can help manage the contaminants present in unconventional North American crude oils.

Hydrocracking: Chevron Lummus Global's (San Ramon, Calif.; www.chevron.com) Natalia Koldachenko presented several examples in which catalyst changes and innovative revamps of hydrocrackers helped realize cost savings.

Hydrogen production: Teams from Linde (Munich, Germany; www.linde.com), Air Products (Allentown, Pa.; www.airproducts.com) and Johnson Matthey all made presentations highlighting the challenges and opportunities associated with the production of refinery H_2.

Process safety: Brian Flis, of Wilson Perumal & Co. Inc. (Dallas; www.wilsonperumal.com), discussed the importance of individual behaviors in the pursuit of incident-free operations.

Workforce challenges: Angie Gildea from KPMG (Amstelveen, the Netherlands; www.kpmg.com) outlined a set of strategies for talent management, and for addressing complicated personnel issues, such as an aging workforce, a gap in the number of mid-career professionals, a growing millennial demographic and others.

Operations: David Wilson from Flint Hills Resources (Wichita, Kan.; www.fhr.com) presented best practices for optimizing communications within the refinery operations team, and the challenges of change management.

Reliability: The duo of Dan Cameron from Tesoro (San Antonio, Tex.; www.tsocorp.com) and Mark Parris from Shell International Ltd. (The Hague, the Netherlands; www.shell.com) made a presentation about how the development of an "ownership culture" can play a key role in continuous-improvement efforts for refinery reliability.

Capital projects: Industry consultant Alan Rossiter (Rossiter & Associates; Bellaire, Tex.; www.rossiters.org) presented tools to improve the economics of capital projects by reviewing process flow diagrams to identify opportunities for efficiency improvement.

Catalyst demonstrations. Kent Turner, of Grace Catalysts, presented results from a field study of Grace's newest FCC bottoms-upgrading catalyst, MIDAS Gold. When used at the Placid Refining Co. facility in Port Allen, La., the MIDAS Gold catalyst allowed greater conversion of resid and increased production of liquid fuels. The company says developments in optimizing porosity of the catalyst matrix and incorporation of metals traps are responsible.

new strategies for increasing gasoline quality, in terms of sulfur content and research octane number (RON). RON attempts to quantify the degree of compression that a fuel can withstand before igniting. Higher-RON fuels exhibit higher performance and less engine knocking in vehicle engines. Among the strategies for increasing gasoline RON is to blend it with alkylate.

The alkylation unit in a petroleum refinery reacts light olefins, such as propylene, with light iso-paraffins, such as isobutene, with a strong acid catalyst (conventionally sulfuric acid). The resulting mixture of branched-chain paraffinic hydrocarbons can be used as a gasoline blendstock to boost octane number. Conventional alkylation units use mechanical agitation to effect contact between the catalyst and the reactants.

At the AFPM meeting, Stephen Williams from CB&I (The Hague, the Netherlands; www.cbi.com) discussed CDAlky, the company's low-temperature sulfuric-acid alkylation process. The process features a novel reactor design, which retains the established chemistry, but improves the mass transfer of the process compared to the conventional equipment. CDAlky uses proprietary static reactor internals, rather than mechanical agitation, to achieve intimate contact between hydrocarbon and acid catalyst, Williams explains. The technology has numerous advantages, including the elimination of the caustic and water wash steps, which reduces chemical costs and environmental impacts. Further, Williams says, the low-temperatures reactor reduces side reactions, boosting octane number. Also, since water is not added to the alkylate product, corrosion is reduced in the product fractionation section, and reliability is improved.

After operating in CB&I's Texas demonstration facility, the CDAlky process entered commercial service in 2013, with a successful installation in Shandong Province, China. Three units are now operating in China, CB&I says, and another two are in engineering stages. CDAlky can be introduced as part of a revamp of existing alkylation units, the company adds.

Ilya Aranovich, isomerization technology manager for GTC Technologies discussed another technology for boosting RON in gasoline. A new isomerization technology in the Isomalk family, known as Isomalk-4, is designed to convert C7 normal paraffins to branched-chain hydrocarbons with significantly higher octane numbers. Isomalk-4 uses a mixed-metal-oxide catalyst similar to those in the previous Isomalk technologies.

"Refiners are continuously searching for ways to generate more value-added products," says GTC Technologies' Bridgeman, "and Isomalk-4 represents a method refiners can use to better utilize the relatively low-value C7 product stream." ■

Scott Jenkins

For more on petroleum refining, see "Tight-oil Tightrope for U.S. Refiners" (*Chem. Eng.*, May 2014) and "Petroleum Refining Outlook" (*Chem. Eng.*, May 2013) at www.chemengonline.com

Improved Particle-Size Analysis Boosts Quality

Particle-size analysis methods are changing for the better, reducing rework and improving yield

IN BRIEF

Particle-size analysis plays an important role in many chemical processes that involve dry powders and granules, fibers, suspensions, emulsions, gels, sprays, inhalants and the like. Processors rely heavily upon particle-size analysis to improve the quality of the product, reduce rework and increase yield. As such, providers of both laboratory and in-situ particle-size analyzers are incorporating modern conveniences, such as automation and intelligence, into existing technologies, as well as introducing systems with advanced analysis techniques, to help processors achieve their goals.

Needs and challenges

When it comes to particle-size analysis, whether the system is laboratory scale or in situ, the essential need is to provide reliable measurement data. "This means accurate, reproducible (repeatability of measurement) and comparable results, both system-to-system results and site-to-site comparability, in the shortest measuring time," says Torsten Huebner, sales manager, Europe, and instrument manager, laser diffraction, with Sympatec GmbH (Clausthal-Zellerfeld, Germany; www.sympatec.com). "Good measurement results depend upon representative sampling and sample preparation, a perfect dispersion down to the primary particles in their original state and, finally, the analytical instrumentation for size and shape characterization."

Ease of operation and efficient analyses are also important for both laboratory and in-situ systems. "In today's [laboratories], a technician is operating many different kinds of measuring systems. Standardized operational procedures have to be available to ensure consistent, high-quality measurements, independent of the operator. And, efficiency and speed of analysis are always a factor. If measurement data are used to control a process, speed of analysis becomes even more crucial and realtime data are desired for close control," explains Huebner. "If the measurement system is integrated into a production process, robustness and system availability are of highest interest in order to prevent downtime."

Stepping it up in the laboratory

When it comes to laboratory analysis equipment, Tim Calvo, laboratory equipment product manager, with Hosokawa Micron Powder Systems (Summit, N.J.; www.hmicronpowder.com), says the majority of his customers are looking for a fast, reliable and repeatable method of particle-size analysis. For this reason, he says, air jet sieves are often the equipment of choice. He adds that while air jet sieving has been available since the 1960s, the technology continues to evolve. "New models have integrated analysis computers, touchscreen displays and automated on-screen instructions, which greatly reduce the need for operator subjectivity," explains Calvo.

For example, Hosokawa's Mikro Air Jet Sieve, Model MAJS-x (Figure 1), is a particle-size analyzer designed for determining the particle-size distribution of dry powder rang-

Hosokawa Micron Powder Systems

FIGURE 1. The Model MAJS-x Air Jet Sieve particle-size analyzer was designed for determining the particle-size distribution of dry powder ranging from 20 to 4,750 µm

ing from 20 to 4,750 µm. The system employs a pneumatic sieving principle that enables accurate and repeatable particle-size analysis. Features, such as an integrated analysis computer with touchscreen control, user-friendly software with step-by-step instructions, a built-in automatic pressure differential gage and automatic data recording and storage with network capability also make the unit easy and efficient to operate.

Paul Kippax, product group manager with Malvern Instruments (Malvern, U.K.; malvern.com), agrees that efficiency of speed and analysis are important. "Within an R&D environment, and especially in the QC [quality control] setting, productivity is vital," he says. "An instrument must deliver reliable data, quickly, to whomever uses it, and for a wide range of samples. So flexibility, ease of use and speed-to-result are all critical characteristics. We can use the phrase 'gloves-on operation' to summarize what many chemical processors are looking for – and that is the need for a fully automated system that even a relatively unskilled operator can simply walk up to and use."

"That said," he adds, "assurances of data quality are equally important, particularly when an analysis is performed by many different people and, perhaps, at different sites around the world. Tools that support the development of robust methods that can be securely transferred, and then provide the ability to test the quality of any data generated during method use, can all be helpful in addressing these concerns."

Malvern's Mastersizer 3000 laser diffraction particle-size analyzer delivers rapid, accurate particle-size distributions for both wet and dry dispersions with minimal effort. It was designed to lighten the analytical burden associated with routine particle sizing so it has many features that accommodate these needs. The features range from interchangeable plug-and-play dispersion modules that make it easy to switch between different sample types to sophisticated software that supports every part of the analytical process, from method development through day-

to-day measurement.

For example, the software includes an optical property optimizer that makes it easy to check the sensitivity of a measurement to analysis parameters during method development, and a data-quality assessment tool that warns the operator if there is anything about the measurement that suggests it may be unreliable.

In addition to quick and easy, Matt Rhyner, global product line manager for characterization with Beckman Coulter (Miami, Fla.; www.beckmancoulter.com) adds high-quality data to the list of what some users of laboratory equipment are seeking. "As material sciences and chemistries advance over time, the materials themselves have become costlier per pound and the end-users have very tight performance specifications from their suppliers," he explains. "Processors of these very exotic materials need high-quality, accurate measurement to meet QC specifications. Having access to high-quality measurement data provides higher confidence and reduces refusals and returns from their customers."

Beckman Coulter's LS Series is a sophisticated and versatile laser diffraction particle-size analyzer. The LS 13 320 MW differs from other laser-based instruments by virtue of its wide dynamic size range, number of size channels and sample measurement options. The laser-based technology permits analysis of particles without the risk of missing either the largest or smallest particles in a sample in dry, aqueous and non-aqueous applications.

And for analyses in wet processes stages, a newer methodology — ultrasonic extinction — has captured a number of applications. "Unlike optical methods like laser diffraction or image analysis, ultrasonic extinction is capable of particle-size and concentration analyses in highly loaded (opaque) suspensions and emulsions without any dilution," says Sympatec's Huebner. "This principle is unrivaled for many tasks in chemical processing, such as crystallization or polymerization."

The company's Ultrasonic Extinction unit with OPUS (Figure 2) is deployed for particle-size-distribution and concentration analysis in turbid and highly concentrated suspensions and emulsions within a size range from below 0.1 µm up to 3,000 µm. Disperse media that is impenetrable for light waves is now penetrated by low energetic sound waves and analyzed using a sample-specific extinction function. This means there is no need for laborious sample preparation.

Sympatec

FIGURE 2. The Ultrasonic Extinction unit with OPUS is deployed for particle-size distribution and concentration analysis in turbid and highly concentrated suspensions and emulsions

The demand for in-situ analysis

Even with today's accurate and fast laboratory analysis options, there are times when processors need more from their particle-size analysis systems. "There are situations where taking a sample and looking at it offline could be problematic," explains Des O'Grady, market manager for particle-systems characterization with Mettler-Toledo AutoChem (Columbia, Md.; www.mt.com). One of the most pressing issues is the inability to sample in some processes, such as those that are under pressure, operate at high temperatures or are explosive or toxic. Another problem, says O'Grady, is that particles may change after you take the sample and transport it to the laboratory. "For example, if you take a sample of crystals at elevated temperatures and it cools down by the time you get it to the laboratory analyzer, what you're looking at offline could be significantly different from the particle that's actually in process." And, there is sometimes an issue with knowing when and how often to take a sample so that it provides an accu-

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rate characterization of the particles throughout the entire process.

But possibly the most significant gain experienced through in-situ analysis is the ability to achieve feedback in real time, says Jason Noga, product marketing specialist, with Microtrac (Montgomeryville, Pa.; www.microtrac.com). "Many of our customers are looking for the capability that provides feedback in real time for better process control," he says. "This allows them to see process swings immediately, enabling them to be proactive, rather than reactive, with their corrective actions, which can produce higher quality products, reduce rework, decrease wasted product and increase yield."

However, some processors encounter challenges when transitioning from laboratory analysis into in-situ analysis. "It's a very different experience of doing something in the lab versus doing something online," explains Ian Treviranus, product line manager for particle characterization in the Americas with Horiba Scientific (Irvine, Calif.; www.horiba.com/particle). "There are two ways to go about transitioning to online measurement. The first is to take a version of technology used in the laboratory and adapt it to your process via enclosures and other modifications. The second approach is to build a specialized online version of the technology that makes the most sense for the application."

Horiba Scientific

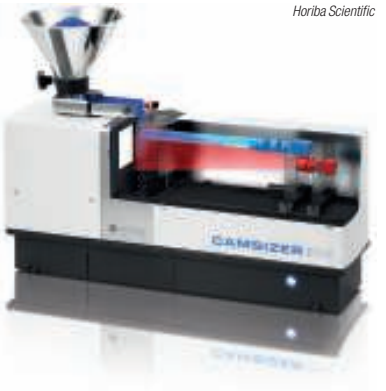

FIGURE 3. Using dynamic image-analysis technology, the Camsizer P4 Online system provides rapid and precise particle-size and shape distributions for dry powders and bulk material

With that approach in mind, Horiba distributes an online version of the Camsizer P4 Particle Size and Shape Analysis System (Figure 3), a laboratory instrument manufactured by Retsch Technology GmbH (Haan, Germany; www.retsch.com). Using dynamic image-analysis technology, the Camsizer P4 Online system provides rapid and precise particle size and shape distributions for dry powders and bulk material in the size range from 20 µm to 30 mm. Because it scans all of the particles using a patented two-camera design, as well as advanced fitting algorithms, the measured results are fully compatible with those of sieve analysis, with which most processors are already familiar, says Treviranus. The instrument is integrated into an industry-standard housing, which makes it suitable for very rough environments and with the available interfaces, it is possible to connect the instrument to process control systems, internal networks and to transfer measurement data.

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As a result, remote control and automatic data transfer are possible.

Noga, at Microtrac, says his company also eases the transition to online measurements using laboratory instrumentation adapted for use in-situ. The company's PartAn 3D laboratory analyzer is now available as the PartAn 3D PRO for process applications (Figure 4). This dynamic image-analyzer technology can measure 36 morphological parameters, including size, shape, surface roughness, sphericity, transparency and 3D in one fast analysis of particles ranging in size from 15 µm to 35 mm.

Once the decision to take in-situ measurements has been made, there are still challenges to deal with, according to the pros. "First you need small instrumentation to go inside the process, and because reliability and uptime are of importance, the probe must be able to provide reliable measurements," notes O'Grady. "Especially in applications that involve crystallization, super-saturation may foul or blind some probes, making it difficult to take measurements."

Microtrac

FIGURE 4. The PartAn 3D PRO for process applications uses dynamic-image-analysis technology to measure 36 morphological parameters, including size, shape, surface roughness, sphericity, transparency and 3D in one fast analysis

In addition, he says, the ability to support data analysis and data interpretation is important. For this reason, Mettler-Toledo AutoChem has been working on a probe-style design that includes intelligence. The company's ParticleView V19 with PVM (Particle Vision and Measurement) technology is a probe-based video microscope that visualizes particles and particle mechanisms as they exist in process. High-resolution images are continuously captured under a range of process conditions without the need for sampling or offline analysis. A process trend, sensitive to changes in particle size and concentration, is automatically combined with the most relevant changes, providing processors with a straightforward and reliable method to ensure comprehensive understanding of the analysis.

While there are some obvious differences between laboratory and process particle-size-analysis systems, either method needs to work in your specific process, so in addition to determining whether to take measurements in the laboratory or in situ and what methodology best serves your needs, it's important to look for a system that is robust, reliable, flexible and includes automated intelligence, if improving product quality and reducing rework are among your processing goals. ■

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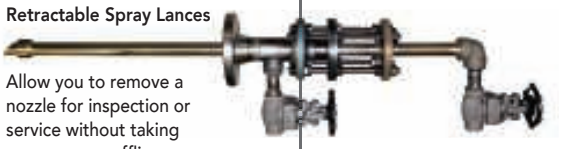

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Flowmeters

Aalborg Instruments

Compact flowmeter manages up to six common plant gases

The ZFM Mass Flow Meters (photo) provides multigas, multirange functionality to 8 bars. This device currently handles up to six gases: nitrogen, air, oxygen, argon, helium and carbon dioxide). When the instrument is connected to the RS-232/RS-485 port of a PC or laptop, the accompanying ZFM configuration utility software lets the user select different gas types and flow ranges without removing the instrument from the installation. This flowmeter provides extensive self-diagnostic capabilities, and has an automatic sensor zero-offset adjustment (via digital interface or local pushbutton control), a digital interface and configuration port (optional Modbus RTU with isolated RS-485 tranceiver), and two programmable totalizers. Seven models are available. — *Aalborg Instruments, Orangeburg, N.Y.*

www.aalborg.com

Alicat Scientific

Use this flowmeter to create customized gas compositions

This company's mass flowmeters and contollers now feature its Gas Select 5.0 firmware and the newly added Gas Select Composer module, which allows users to create highly accurate mixed-gas compositions (photo). Version 5.0 of the firmware includes an expanded library of up to 130 preloaded gas calibrations. In addition to pure gases, Gas Select 5.0 also includes numerous gas mixtures that are commonly used in bioreactor, welding, power, refrigerant and medical applications. The newly added Gas Composer module gives users the ability to quickly program and store up to 20 customized gas compositions directly on the mass flowmeters and related controllers. Using an integrated digital display, users can define gas compositions to 0.01% for each of up to five constituent gases. Up to 20 gas mixtures can be created and stored simultaneously on each device.— *Alicat Scientific, Tucson, Ariz.*

www.alicat.com

Burkert Fluid Control Systems

These flowmeters handle high-volume gases

One of the primary challenges associated with measuring the flow of a gas is that accuracy can be reduced by changes in temperature and pressure. This company recently added two new flowmeters (photo) — Type 8007 (designed for pipe sizes with diameter ranging from 0.5 to 12 in.) and Type 8008 (designed for pipe sizes up to 2 in. in dia.) — to its product offerings. These devices are designed for measuring especially large gas flowrates. They use the calorimetric principle of flow measurement, ensuring that measurement accuracy is unaffected by changes in temperature and pressure, says the company. Because this method of measurement requires no moving parts, these flowmeters deliver overall reliability and high accuracy, even at relatively low flowrates.— *Bürkert Fluid Control Systems, Gloucestershire, U.K.*

www.burkert.com

Simple paddle-wheel device provides visual flow indication

The Kobold DAF is a paddle wheel flow indicator for liquids, and is recommended whenever visual flow indication (without flow measurement) is required. The simple design uses a rectangular housing with two transparent windows containing a paddle wheel that is set in motion by the flowing media. The rotating paddle wheel provides visual indication of flow. Flow ranges are varied by changing the inlet port orifice, allowing the same housing to be used for many flow ranges. It can be installed in any position, as long as the flow remains in the direction of the arrow, says the company. Connections are available in 1/8-in. NPT, with many choices of materials for media compatability. This device can be rotated along its long axis, even during operation, thanks to rotatable fittings, thereby allowing the windows to be easily viewed by operators. — *Kobold USA, Pittsburgh, Pa.*

www.koboldusa.com

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Coriolis flowmeter aims to give users greater process insight

This company's Micro Motion Model 5700 Transmitter (photo) is a Coriolis flow transmitter that is designed to translate measurement data into meaningful insight and instruction. It does this by translating measurement data into, for instance, time-stamped history files for process and meter health data, and logs of configuration changes and alarms. It is designed for a range of applications, from liquid and gas transfer to simple process control. It was designed to be easy to use and easy to install. The Model 5700 provides users with access to detailed measurement history for troubleshooting or optimizing the process. The user interface allows for intuitive operation, with simplified installation, configuration, maintenance and troubleshooting.— *Emerson Process Management, Orlando, Fla.*

www.emersonprocess.com

Emerson Process Management

Thermal mass flowmeters regulate N_2 tank blanketing

Fluid Components International

Nitrogen tank blanketing is widely used to protect stored contents, to prevent contamination, and to reduce the risk of toxic fume leaks, fires and explosions. This company's ST Series Flow Meters (photo) are mass flowmeters that are available in a wide array of designs to accommodate various tanks and line sizes. Installed upstream of the tank's regulator valve, these flowmeters ensure accurate measurement, monitoring and control of the blanketing gas to ensure safe, economical operation. These mass flowmeters are calibrated to specific gases (nitrogen or others) in the company's NIST-approved calibration laboratory, and their thermal dispersion mass flow sensors and rugged packaging are suitable for a wide range of industrial process environments. — *Fluid Components International, San Marcos, Calif.*

www.fluidcomponents.com

Vortex flowmeter can assist with energy-saving efforts

The new Optiswirl 4200 vortex flowmeter is designed for the measurement of conducting and non-conducting liquids, gases and steam. The devices are suitable for use in auxiliary and supply applications in various industries, such as internal monitoring of energy

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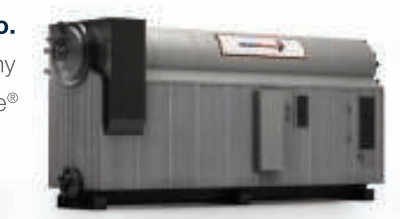

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flows for saturated and supersaturated steam and hot water, and heat-metering applications. In addition to gross heat calculation for steam, the Optiswirl 4200 (photo) now includes net heat calculation for steam and condensate, as well. With one temperature sensor integrated as standard, the device can be installed as a heat meter in the feed line, directly connected with an external temperature sensor in the return line. The gross and net heat calculation can be fed into a DCS for advanced energy management. Another advantage, says the company, is that by combining three measurements (flow, temperature and pressure) in one two-wire device, the line has to be opened only once for installation. — *Krohne, Duisburg, Germany*
www.krohne.com


Krohne

Define gas flowrates in the field or in the laboratory


New Star Environmental

The Definer 220 flowmeter (photo) allows users to verify gas flowrates in the laboratory or in the field, to an accuracy of ±1% of reading, including temperature and pressure compensation. Unlike thermal mass flowmeters, the Definer 220's positive-displacement technology provides immediate indication of actual volumetric gas flowrate, accurately and independently of the gas type, says the company. Integrated temperature and pressure sensors in the flow stream allow users to automatically standardize volumetric flow readings to standard conditions. — *New Star Environmental, Roswell, Ga.*
www.newstarenvironmental.com

The flow totalizer device tracks flare operation

Signal Fire

This company's Totalizer Module (photo) works with analog or digital flowmeters to provide instantaneous total and daily flow information related to gas flares. With a built-in, user-configurable, realtime clock, the wireless Totalizer Module stores data related to the last 30 days of total flow values. Data can be accessed wirelessly when connected to an integrated device that combines a high-gain antenna with gateway electronics in a single, easily mounted package, or locally over an RS-485 Modbus RTU connection. — *Signal Fire, Hudson, Mass.*
www.signal-fire.com ■

Suzanne Shelley

Additional flowmeters are profiled in the online version of this article, at www.chemengonline.com

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New Products

This remote user interface is now hazardous-location certified

The EZ-Zone EZK (photo), a remote user interface (RUI) that can also be used as a communication gateway, is now available with an option for Class 1, Division 2, temperature class T4A, for use in hazardous locations. The EZ-Zone RUI can be utilized as a communications gateway device to save cost, space and wiring when digital communications are being used with two or more EZ-Zone controllers. It can also serve as a display for showing all parameter values for up to 16 EZ-Zone controllers, which helps improve the user-system interface. As a communications gateway, the RUI can deliver multiple communication protocol options. The device's T4A temperature classification means that its surface temperature will not rise above 248°F (120°C). — *Watlow Electric Manufacturing Co., St. Louis, Mo.*
www.watlow.com

Use these ribbed burst panels in vacuum conditions

This newly launched ribbed bursting panel (photo) ensures that safe operations are maintained when low to medium levels of vacuum are present. The panel's unique design can withstand vacuum or backpressure of up to 40% of the minimum burst pressure, making it suitable for many standard applications, such as silos and bucket elevators, where the dusty conditions commonly associated with the storage and handling of grains and powders can potentially lead to dangerous explosions. The non-torque-sensitive panel has a low-profile, space-saving design, and is available with the optional benefit of an integral burst-detection system for instantaneous notification when the panel has functioned. — *Elfab Ltd., North Shields, U.K.*
www.elfab.com

Measure lubricating-oil viscosity with extremely small samples

The new microVISC-m viscometer (photo) is designed to simplify daily or routine measurements of lubricating oils' viscosity. Requiring only a few drops of oil, the microVISC-m measures oil viscosity through an easy, one-minute test, eliminating the need to wait for test results from remote laboratories. The instrument requires a sample volume as small as 100 µL, and displays dynamic viscosity at ambient conditions. It also extrapolates kinematic viscosities at 40, 80 and 100°C, following industry-standard formulas. — *RheoSense Inc., San Ramon, Calif.*
www.rheosense.com

Latest software release builds on existing capabilities

The latest release of Diagrams software was introduced in March. Diagrams is engineering software that enables the creation and delivery of intelligent piping and instrumentation diagrams (P&IDs) and other schematics. This software update will enable engineers to collaborate more efficiently on multi-discipline projects, thereby eliminating errors and inconsistencies that could otherwise lead to costly subsequent rework, says the company. The new version includes enhancements that can enable engineers to optimize their use of Diagrams, requiring fewer iterations to develop a final, fully compliant and accurate schematic design, says the company. — *Aveva Solutions, Ltd., Cambridge, U.K.*
www.aveva.com

Achieve vapor-pressure testing for up to 12 samples in one run

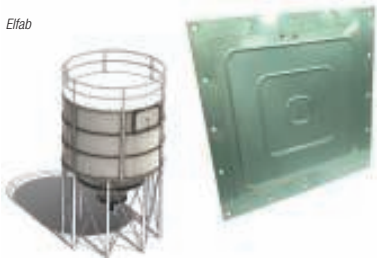
The newly introduced RUN12 Auto Sampler (photo) can achieve rapid and continuous vapor-pressure testing of up to 12 samples in one run. The Auto Sampler's corrosion-resistant construction makes it suitable for testing plain or aggressive samples filled from tubes out of a bottle or from attached syringes. The sampler includes Sampling Pro technology, a valve design that minimizes the risk of cross-contamination between different sample types. Optional tapwater cooling allows sample transfer for various vapor-pressure methods. — *Ametek Grabner Instruments, Vienna, Austria*
www.grabner-instuments.com

A solid-state relay with fast release times and little noise

The RV8S solid-state interface relay (photo) boasts a compact 6-mm

Watlow Electric Manufacturing

Elfab




RheoSense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footprint, and features high switching cycles, extended operating life and high-speed load switching. Common uses of the RV8S include general load switching in control systems for assembly machines, solenoids, molding machines and other applications requiring a high repetition rate. The RV8S has operate and release times that are much faster than electromechanical relays. The relay also generates no acoustic and far less electrical noise than its electromechanical counterpart because it makes use of semiconductor outputs instead of electrically sparking contacts. The RV8S can safely operate in temperatures from –20 to 60°C and humidity from 5 to 85%. — *IDEC Corp., Osaka, Japan*
www.idec.com/usa

Microprocessor-based gas monitors with custom sensors

Enmet

The GSM-60 (photo) is a microprocessor-based gas monitor especially designed for use in industrial process, aerospace, pharmaceutical and semiconductor applications. The system incorporates an internal sample-draw pump and gas sensors. The instrument can be custom-configured with both internal and external sensors for monitoring a combination of gas parameters, including volatile organic compounds (VOCs), dewpoint, oxygen and carbon monoxide, or a number of other target gases, such as O_3, HF, HCl and Cl_2. As an option, this monitor can also be connected to a wide range of remote 4–20-mA sensors or transmitters for toxic or combustible gases. — *Enmet LLC, Ann Arbor, Mich.*
www.enmet.com

A high-pressure microreactor for small-batch chemistry

Supercritical Fluid Technologies

The HPR-Micro Reactor (photo) is a high-pressure reactor specifically designed for small-batch reaction chemistry, and is well suited for research, process-development and screening applications when reagents, catalysts or other essential materials are expensive or available in very limited supply. The HPR-Micro Reactor comes standard with a 10-mL reactor vessel for operation up to 10,000 psi, inlet and outlet valves and a pressure gage. Optional 25-mL and 50-mL vessels are also available. Depending upon the temperature option selected, operation from –40 to 150°C is possible. The vessel closure is hand-tight, so no wrenches are needed. The reactor is equipped with magnetically coupled stirring for optimal mixing, and the overall assembly is protected by a rupture-disc assembly. Multiple inlet ports are included for addition of solvents, reagents or gases. — *Supercritical Fluid Technologies, Inc., Newark, Del.*
www.supercriticalfluids.com

Improve ergonomics with these vertical work positioners

Verti-Lift

This company's line of hydraulic and pneumatic work positioners (photo) keep workpieces close at hand and eliminate unnecessary reaching and other operator movements, thus enhancing ergonomics. These positioners are available in various lift capacities, base and turntable sizes. With the inclusion of a heavy-duty, 360-deg turntable, they are suitable for many applications, including palletizing, de-palletizing, workstation assembly and manufacturing. Many options are available, including accordion skirting, oversized platforms, platforms with beveled edges, pit-mounted units, portability packages, foot-pedal control, fork pockets, external power modules and more. — *Verti-Lift Inc., Louisville, Ky.*
www.verti-lift.com

Faster startup times with these graphic terminals

Rockwell Automation

The new Allen-Bradley PanelView 800 family of graphic terminals (photo) is designed for a faster startup time, reportedly two times faster than previous models. Available in 4-, 7- and 10-in. display sizes, the panels offer improved touchscreen responsiveness and can be configured in portrait and landscape mode for greater installation flexibility. Built-in Ethernet- and serial-communications ports support controller connectivity. The terminals are also certified for Class 1, Div. 2 hazardous locations. — *Rockwell Automation, Milwaukee, Wis.*
www.rockwellautomation.com

Introducing pH sensors that are able to learn

Mettler Toledo

Not knowing when pH sensors will require maintenance or if a sensor is going to fail unexpectedly can be a problem. A solution (photo) to this problem comes in the form of the trademarked technologies, Intelligent Sensor Management (ISM) and Sen-

sors That Learn. New ISM algorithms allow pH sensors to actually learn from the conditions in a process. Sensors That Learn delivers more accurate sensor-health diagnostics more quickly than previous versions, and enhances the consistency of sensor-lifetime information. When an ISM sensor is connected to a PC running the iSense software, all relevant data are displayed on the software's iMonitor screen, allowing evaluation of the probe. — *Mettler Toledo AG, Urdorf, Switzerland*
www.mt.com/pro

Robot-assisted measurements of surface free-energy

At the Hannover trade fair last month, this company introduced its Large Surface Analyzer (LSA; photo), a positioning robot combined with the Mobile Surface Analyzer (MSA) contact-angle measuring instrument. The system performs fast, fully automated surface free-energy (SFE) determinations at freely defined positions on large samples. The system

Krüss

is particularly well suited to quality-assurance applications on cleaned, pretreated or coated materials. — *Krüss GmbH, Hamburg, Germany*
www.kruss.de

A new ultrasonic flowmeter for superheated steam

Krohne Messtechnik

The Optisonic 8300 (photo) is a dedicated ultrasonic flowmeter for the measurement of superheated steam. The two-beam flowmeter delivers a measuring accuracy of 1%, high repeatability and a large dynamic-measuring range. Built for longterm use, the device features a full-bore flow sensor without moving parts or obstructions, and an overall sturdy and robust construction with no cables or sensitive parts exposed. Therefore, it can uphold its measuring accuracy without maintenance or subsequent calibration for up to 20 yr, says the manufacturer. With nominal sizes ranging from DN 100–1,000, Optisonic 8300 is particularly suited to high flowrates. Pressure and temperature ratings are up to 200 bars and 540°C, respectively. — *Krohne Messtechnik GmbH, Duisburg, Germany*
www.krohne.com

These interlocks withstand temperatures over 1,800°F

In recent tests, the GL and QL interlocks (photo, p. 46) withstood temperatures of up to 1,830°F (1,000°C). Performed by Score Group plc, the tests found the QL and GL to be

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compliant with the temperatures and conditions specified in API Standard 607 6th Edition — 2010 and ISO 10497:2010. The tests verified that, in the event of a fire, the hardware will continue to function and the integrity of the locking mechanism will be maintained. During the test, the lock had one key inserted and one free; following cooldown, the lock remained secure on the valve. Only when the other key was inserted could the lock be moved to the open/closed position, as should happen. — *Smith Flow Control USA, Erlanger, Ky.*
www.smithflowcontrol.com

Miniature thermometer for sterile processes gets Ex approvals

The TR21 miniature resistance thermometer (photo) is currently the only instrument on the market that combines a housing of only 19-mm dia. with explosion protection, claims the manufacturer. The measuring instrument, developed for sanitary applications, has now obtained ATEX and IECEx approval for the ignition-protection Type Ex i. The combination of compact size, hygienic design and intrinsic safety makes the TR21 a multi-application thermometer for processes in the food and pharmaceutical industries. The TR21 has a measuring range from –50 to 250°C, and is delivered with a direct sensor output (Pt100) or integrated transmitter (4–20-mA output). The sensor can be calibrated without having to open the process. — *WIKA Alexander Wiegand SE & Co. KG, Klingenberg, Germany*
www.wika.de


WIKA Alexander Wiegand

A compact liquid flowmeter for industrial applications


Sensirion

The new SLS-1500 liquid flowmeter (photo) delivers fast and precise measurements for flow rates of 0 to 40 mL/min. The device comes in a robust housing and is suitable in demanding industrial environments and laboratory settings. With a typical response time of 20 ms, the SLS-1500 is able to monitor highly dynamic dispensing processes. The flow channel inside the sensor is completely straight and open and has no moving parts. Inert wetted materials provide outstanding chemical resistance and excellent biocompatibility. The SLS-1500 is compatible with SCC1 interface cables, and thereby various output connections. — *Sensirion AG, Staefa, Switzerland*
www.sensirion.com
Mary Page Bailey and Gerald Ondrey

Catalysis Fundamentals

Department Editor: Scott Jenkins

Catalysis is among the most important chemical phenomena in industrial chemistry, as well as in many biological and research fields. This one-page reference provides a review of several of the fundamental concepts underlying catalysis.

Catalyst basics

A catalyst interacts with chemical reactants to increase the reaction rate. Catalysts form fleeting intermediate chemical complexes with reactants, allowing the reaction to follow a different mechanistic pathway that requires lower activation energy (E_a) than the corresponding uncatalyzed reaction.

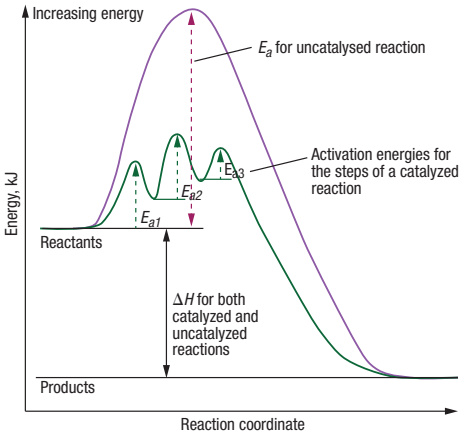
E_a is often thought of as an energy barrier over which the reactants must pass to form products. Activation energies are often shown on graphs that plot reaction coordinate against thermodynamic free energy (Figure). Reaction coordinates are one-dimensional representations of the progress of a chemical reaction.

Catalysts are broadly categorized as homogeneous or heterogeneous. Homogeneous refers to those catalysts that are dissolved in the reaction medium, forming a single phase with the reactants. Heterogeneous catalysts exist as a distinct phase from the reaction mixture and are often porous solid particles.

Both categories are important for industrial chemistry. Examples of liquid-phase, acid-base-catalyzed reactions include hydrolysis of esters and amides, enolization of aldehydes and ketones, esterification of alcohols, halogenation of acetone and others. Heterogeneous catalysts play a key role in the production of petrochemicals, including cracking, alkylation, polymerization, isomerization, dehydrogenation and many others.

Mechanism of action

Most chemical reactions involve simultaneous (rather than sequential) bond breaking and bond forming. Along the pathway of reactants to products, the molecules adopt a configuration that represents the highest potential energy state, known as the transition state. The transition state is characterized by bonds that are both partially formed and partially broken. Catalysts form an intermediate species with one of the reactants and stabilize the transition state, allowing the reaction to proceed with a mechanism that requires lower energy. As products form, the catalyst is regenerated.



Catalyst features

The following summarizes key catalyst characteristics:

Reversible reactions. In the case of reversible reactions, the catalyst acts on both the forward and reverse reactions. The catalyst does not affect the position of the equilibrium, but it does accelerate the rate at which equilibrium is reached.

Energy. The presence of catalyst does not affect the potential energy of the reactants or products. It affects only the activation energy.

Selectivity. In reactions with multiple feasible mechanisms, catalysts can often exhibit selectivity by binding to the transition state in a way that favors one reaction pathway over others. Catalyzed reactions often show a different product distribution than the same uncatalyzed reaction.

Reaction rate. In homogeneous-catalyzed reactions, the reaction rate is generally proportional to the concentration of the catalyst, while in heterogeneous catalysis, the reaction rate is proportional to the surface area of the solid catalyst and the concentration of active centers (catalytic sites).

Solid-catalyzed reaction steps

Solid-catalyzed, fluid-phase chemical reactions generally undergo the following steps:

1. ***Diffusion.*** Reactants in the fluid phase diffuse to the exterior surface of a catalyst particle and into the catalyst pores
2. ***Adsorption.*** Reactants adsorb to the active centers in catalyst pores
3. ***Reaction.*** The surface-adsorbed reactants form products
4. ***Desorption.*** The product molecules desorb from the exterior surface of the catalyst pores
5. ***Diffusion.*** Product molecules diffuse back into the bulk fluid

In most cases, one of these steps contributes most significantly to the overall reaction rate, and often the others steps can be ignored or combined when determining reaction rates. The significance of each step depends heavily on the reactants and the reaction conditions.

Influencing factors

The following are factors that can play a large role in determining which step is more or less significant:

- Fluid-dynamic factors
- Catalyst properties (such as particle size, porosity, pore geometry and surface characteristics)
- Diffusion characteristics of fluid reactants and products
- Activation energy requirements for adsorption and desorption of reactants and products to and from solid surfaces
- Overall E_a of the catalyzed reaction
- Thermal factors (temperature and heat-transport characteristics)

References

1) Perry, R.H. and Green, D.W., "Perry's Chemical Engineering Handbook," 7th ed., McGraw Hill Professional, Section 4, Chapter 12. 1997.

2) Wijngaarden, R.J. and others, "Industrial Catalysis: Optimizing Catalysts and Processes," Wiley-VCH, Weinheim, Germany, 1999.

3) University of Texas, Chemistry 302. Course material on chemical kinetics. Accessed from ch302.cm.utexas.edu, April 2015.

Hydrogen Production from Natural Gas

By Intratec Solutions

Hydrogen (H_2) is an important chemical feedstock, mainly applied in the manufacture of ammonia and methanol, and for hydroprocessing operations in petroleum refineries. Also, since H_2 is an energy carrier, it has been considered for stationary power and transportation applications.

Hydrogen production technologies are separated into three main categories: thermal, electrolytic and photolytic. In thermal processes, such as reforming and gasification, H_2 is produced from biomass and fossil fuels, such as coal and natural gas. In electrolytic processes, H_2 is obtained from water-splitting, using electricity that can be generated from a variety of sources, such as wind. In photolytic processes, light energy allows hydrogen production using novel photoelectrochemical and photobiological water-splitting processes.

In the U.S., H_2 is mostly produced from natural gas using the thermal steam methane reforming (SMR) process. Natural gas is an important feedstock for H_2 production since it is widely available and presents a high hydrogen-to-carbon ratio, reducing the generation of carbon dioxide (CO_2) byproduct.

The process

In the process described below and depicted in Figure 1, H_2 is produced from natural gas using an SMR process. The process was compiled based on information available in the chemical literature.

Sulfur removal. Natural gas feedstock is purified by catalytic treatment with H_2 for removal of sulfur impurities. In the hydrotreater, H_2 reacts, over a catalyst, with sulfur compounds present in the feed stream to form hydrogen sulfide (H_2S), which is then adsorbed in the desulfurizer.

Steam reforming. Purified natural gas is mixed with high-temperature steam and reformed into CO and H_2. The reforming reaction requires a large amount of heat and takes place in an externally fired tubular reactor filled with catalyst.

Water-gas shift. CO and steam react in a catalytic water-gas shift reaction, forming additional H_2 and CO_2.

Purification. CO_2 and other impurities are removed from the H_2 stream in a pressure-swing adsorption (PSA) system. The purge stream from the PSA system is recycled to the reformer, where it is burned with fuel to provide heat to the reaction. The H_2 product obtained has purities of 99.99 wt.%.

Economic evaluation

An economic evaluation of the process was conducted based on the following assumptions:

- A central facility with a nominal capacity of 450,000 ton/yr of H_2 erected on the U.S. Gulf Coast
- Distribution costs and storage for feedstock and product were not considered

The estimated total fixed investment for the construction of this plant is about $460 million.

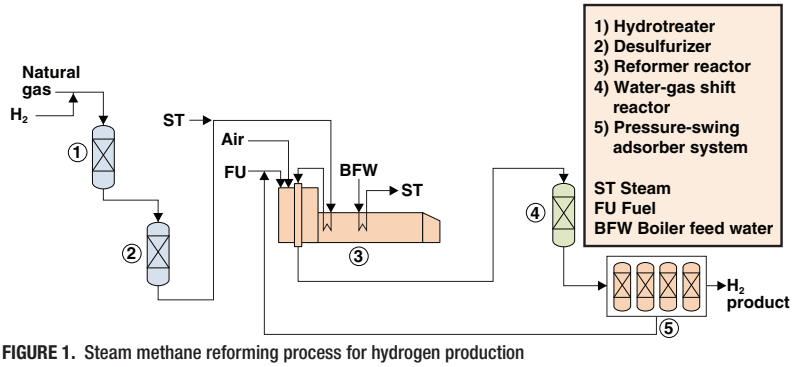


FIGURE 1. Steam methane reforming process for hydrogen production

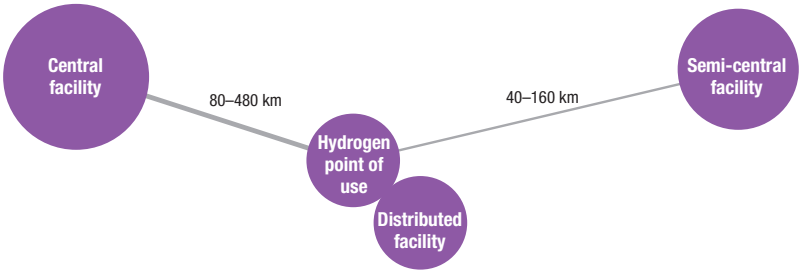


FIGURE 2. There are three types of hydrogen production facilities, and they differ in location and scale of production

Global perspective

There are three kinds of facilities for H_2 production: central, semi-central and distributed facilities (Figure 2). They differ in their location and scale of production, characteristics that directly affect H_2 cost, competitiveness and timeframe to market.

Central facilities are located far from the H_2 point of use and are able to produce large amounts of H_2, benefiting from economies of scale. This type of facility requires high capital investment, as well as a distribution infrastructure able to cover large distances.

Semi-central facilities present intermediate H_2-production capacity. They present reduced distribution costs, since they are sited closer to H_2 points of use.

Distributed facilities are small facilities located close to or at the point of H_2 use, reducing delivery costs. These facilities may present production capacities fitted to local demand. They require less investment than the other facilities, although unit production costs may be higher. ■

Edited by Scott Jenkins

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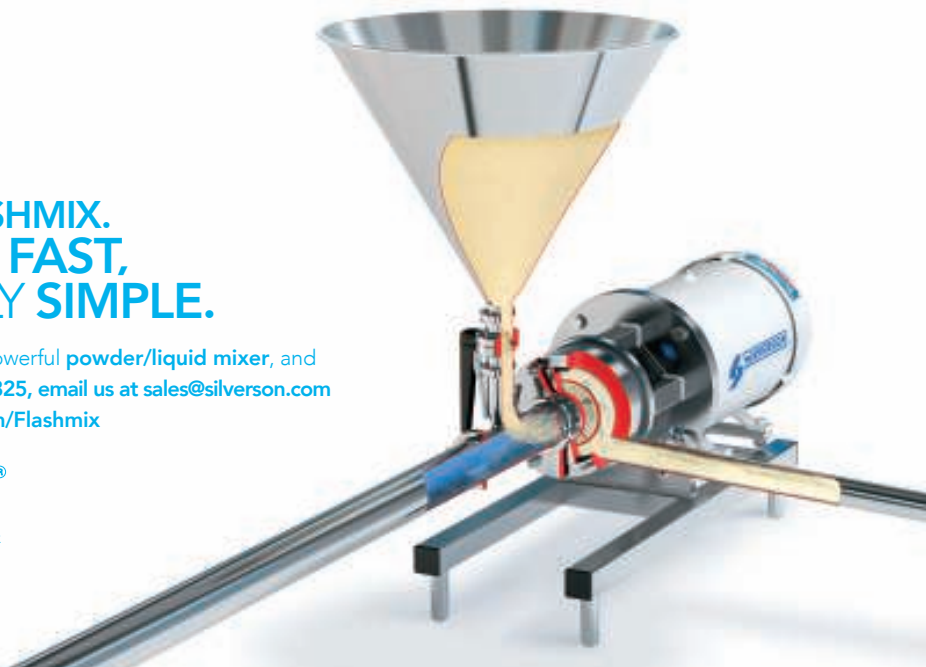

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Managing Large Chemical Plant Startups

Prudent planning and scheduling during a project's front end can lead to more expedient commissioning and startup activities

Mark Sheridan
Consultant

IN BRIEF

FIGURE 1. Seeing a large CPI facility through design, construction, commissioning and, ultimately, startup requires detailed planning throughout, especially during the project's front end

The cost of starting up large new facilities in the chemical process industries (CPI; Figure 1) is a significant element in a project's total finances. Typically these "owner-controlled" costs are budgeted to be 8–12% of the capital project costs, depending on what is included in the project's pre-startup budget. Actual costs vary considerably, depending on how well the pre-startup activities are planned and executed.

Good startup planning and execution can save 1–3% of total project costs — typically something in the range of $10–40 million for projects that are budgeted for $500 million to $2 billion. This stake is large, yet the people managing the startup preparations are frequently inexperienced with this rather specialized work. This unfamiliarity often results in substantial inefficiencies, causing excessive pre-startup costs and delays that frequently exceed budget and reduce first-year profits.

This article describes the steps that should be taken during the front-end planning and the pre-commissioning phase to ensure that work progresses efficiently and that the likelihood of incidents is reduced. These strategies should help realize the expected profitability during the plant's commissioning, startup and initial operation.

Front-end planning

A key element in minimizing startup costs is to begin startup planning on the project's front end. Front-end planning, for purposes of this article, begins during the development of the initial appropriation request and front-end engineering design (FEED), and it continues throughout the period in which the owner's task force takes up residence in the contractor's offices.

Much of the front-end work that is necessary to support successful pre-commissioning, commissioning and startup many months in the future can be summarized

as follows:

- Identifying the resources that are needed from the owner's company in terms of financial and human-resources contributions in order to make the efforts for pre-commissioning through startup a success
- Defining the focus of the owner's task force during the design phase to ensure successful pre-commissioning and commissioning in the future
- Identifying what is needed from the engineering contractor to make the project comply with the owner's standards to support good pre-commissioning and commissioning plans

Owner-controlled costs

While the accuracy of the project's capital estimate is, to a great extent, at the mercy of the contractor, some expenditures are budgeted and spent directly by the owner, and are directly under the control of the owner's project and operations managers. A detailed budget is needed on the project's front end that identifies the expenses that are associated with pre-commissioning, commissioning and startup. This budget is normally developed and authorized as part of the overall project funding, but it is managed by the owner's representatives separately from the project budget that the contractor must meet. An in-depth assessment will identify a large number of budget line items — perhaps 50–100 items — that can vary widely, depending on the location of the new facility, whether the project is a grassroots plant or at an existing site, the type of manufacturing process and the extent of new technology involved.

Some examples of these line items are shown in Table 1. Particular attention should be paid to forecasting the large-dollar line items — usually those related to staffing, raw materials and pre-startup energy and chemical expenses — because these expenses tend to be underestimated. Contingency should also be considered for unforeseen expenses, such as potential project delays. For more information on the importance of contingency in project budgets, see Improve Your Contingency Estimates for More Realistic Project Budgets, *Chem. Eng.*, Dec. 2014, pp. 36–43.

TABLE 1. TYPICAL OWNER-CONTROLLED PROJECT EXPENSES

Staff (until saleable product is produced)
Exempt and non-exempt staff payroll
Site-contracted work, such as security and janitorial staff
Hiring and relocation costs
Project-related travel
Temporary peak-load contract staff
Contractor assistance in pre-commissioning and commissioning
Employee benefits
Consultants (for specialized training, for instance)
Corporate overhead allocations
Office facilities
Rental and operating costs for temporary offices
Operating costs for permanent offices
Office equipment leases and office supplies
Office furniture and related equipment, such as file cabinets
Copying charges
Laboratory instruments, equipment and supplies
Landscaping
Information-technology telephone systems, networks, servers and computers
Software license fees
Maintenance
Rolling stock purchase or lease (cranes, trucks, switch engines and so on)
Stocking non-capital spare parts
Warehouse setup and stocking of consumables
Tool-room stocking
Mobile-radio frequency purchase
Maintenance supplies
Vendor startup assistance
Consultant services
Specialized maintenance services
Commissioning activities
Raw materials cost (until saleable product is made)
Initial inventories of chemicals and in-process materials
Initial catalyst purchases
Non-capitalized operating equipment and supplies
Process training simulator for control-room training
Energy costs for steam generation (line blowing, turbine testing, distillation and so on)
Maintenance vendor support during commissioning
Specialty services, such as chemical cleaning, pipeline blowing or catalyst installation
Costs to operate utility systems during commissioning
Initial technology licensing fees and royalties
Other
Sales-tax accrual
Insurance (property, workman's compensation and so on)
Property tax
Safety, emergency-response and first-aid treatment equipment

Justifying staffing resources

While the owner's senior managers — those who authorize projects and staffing — have a good understanding of the capital costs required for a large project, they frequently do not appreciate the manpower required to successfully bring a major project into operation, or the drain on other company operations if positions are to be filled internally. When this is the case, delays in filling positions as the work expands can

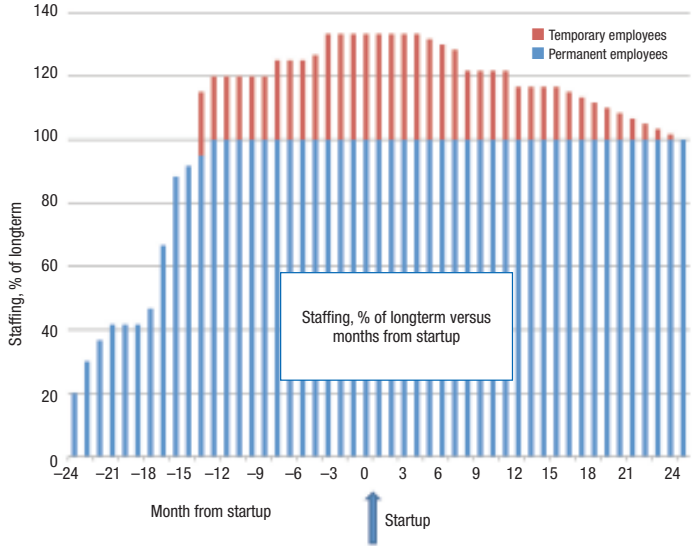


FIGURE 2. It is important that temporary personnel are included in the staffing schedule at times of peak workload to supplement the staff that will eventually be permanent employees

cause major difficulties in accomplishing pre-commissioning work in time for a successful startup.

It is normally up to the project manager or operations manager who is involved in the front-end planning to make the case for adequate staffing prior to project authorization. These individuals should develop a detailed organization chart that shows peak and longterm staffing requirements. This chart will then be used as the basis for budgeted staffing, allowing senior management to begin early planning for succession of internally filled jobs. The chart will also set the groundwork for filling positions in a timely manner as the project progresses from task-force formation through pre-commissioning.

For budgeting purposes, a typical staffing schedule as a percentage of longterm staffing is shown in Figure 2. In addition, there should be contingency planning for additional staffing if needed. Note that professional and supervisory staffing (beyond the owner's design task-force members already committed to the front-end planning) typically precedes operator and mechanic staffing by 2–3 months. This helps to organize the work these employees will be doing once they are hired and assigned to the pre-commissioning teams.

Owner task-force functions

Once a project is authorized and owner representatives become resident in a contractor's offices, the primary function of each member of the owner's task force must be well defined. Identifying these functions will guide what skills and experience the task-force members need, as well as help to determine the proper number of people on the task force. The contractor must also have a good understanding of the task force's functions — this encourages cooperative work with that group during the design and construction phases.

Depending on how well the owner's scope of work for the project is defined, the degree of familiarity the contractor has with the process and the depth of involvement the owner wants in reviewing the design as it progresses, the staffing level of the task force resident in the contractor's offices could be around one task-force member per $25–50 million of capital investment.

After award of a contract to an engineering firm, the task force usually resides at the contractor's offices until the project design is about 40% complete. At this point, this group begins transitioning attention to pre-commissioning preparations and begins relocating from the design offices to the construction site, becoming the nucleus of the facility staffing.

Clarify contractor responsibility

There are several issues that are crucial to a successful startup that must be discussed with a contractor, some prior to awarding a contract. To the extent that the owner feels it advantageous, some of the following activities might be included as elements in the contract:

1. Align the contractor and owner's financial incentives as much as possible. If the contract is incentive-based, the incentive should be based on successful mutual accomplishment of whatever is most financially important to the owner, such as producing targeted volumes by a designated date. Using a project mechanical completion date (a common target for contractor incentives) as the goal is often counterproductive. Having a mutual financial objective promotes mutual design, procurement and construction objectives, as well as harbors a more harmonious relationship between the owner and the contractor
2. To help ensure an operable design and successful startup, identify the activities for which the contractor is responsible, but in which the owner wishes to be involved during the design, procurement and construction functions. Also important to define is which person in the owner's organi-

TABLE 2. TYPICAL DEPARTMENTAL PRE-COMMISSIONING TASKS	
Production	Specify shop equipment and tool-room tools for purchase
Assist in hiring interviews for production personnel	Establish and maintain electrical and instrument (E&I) files
Develop and maintain commissioning schedule	Develop commissioning procedures for electrical distribution system
Write and approve commissioning procedures	Develop commissioning and testing procedures for instrument loops
Develop operator certification process	Develop commissioning procedure for online analyzers
Write and approve operating manuals	Identify gases for analyzer calibration
Develop and conduct operator training	Develop test procedures for safety interlock functions
Oversee process-simulator development	Obtain radio licenses
Assign personnel to jobs	Obtain radioactive source permit
Develop area safety rules	Develop distributed controls system (DCS) graphics
Develop plans for major raw-materials contract administration	Approve DCS system configuration
Develop log sheets	**Process engineering**
Prepare operating budget	Lead process-hazard reviews
Develop emergency-response procedures	Assist with operating manual development
Assign emergency-response teams and conduct training	Administer licensing agreements and related startup assistance
Label all lines and equipment	Create material-safety datasheets (MSDS)
Review and comment on safety and health manual	Develop non-routine operating procedures (for instance, catalyst-reduction processes)
Train production personnel on safety and health procedures	
Train production personnel on transportation, security and safety and environmental regulatory compliance	Develop process-simulation models
	Assess technology questions that arise
Train selected personnel on contracts for feed, utility and products	Set up control and field laboratory equipment and facilities
Train personnel on human-resources policies	Establish control and field laboratory procedures
Establish production file system	Develop operating contingency plans
Develop shift-turnover process	**Accounting**
Develop daily production report	Develop monthly cost-accounting reports
Define days and shift-communication methods	Develop monthly financial closing process
Identify offsite disposal needs	Develop general ledger accounts
Assist in developing process-control graphics	Develop property tax roles
Maintenance	Track non-capitalized project costs versus budget
Witness equipment-performance testing at vendor shops	Audit project invoices from contractor
Participate in construction quality-assurance process	Develop operating budget
Establish and maintain files for equipment, loop and logic diagrams	Develop tax-related procedures
Assist in hiring mechanics	Establish compliance methods for finance-related regulations
Develop and conduct mechanic training	**Safety and security**
Set up spare-parts catalog and order equipment	Develop safety and security procedures manuals
Receive, inspect and stock spare parts and maintenance supplies	Develop training on safety and security procedures
Set up warehouse and equipment storage	Develop regulatory-compliance processes for safety and security
Specify rolling stock (such as trucks and cranes) for purchase	Hire security personnel
Set up mechanical integrity program	Develop emergency-response processes and training
Set up programs for field-reliability checks	Establish offsite contacts for emergency response
Establish work-order process	Compile MSDS database
Develop job plans for selected jobs	Establish compliance methods for safety and security regulations

Note: Similar responsibilities lists should be developed for human resources, environmental, purchasing, site project engineering, logistics and other site groups

zation holds approval rights where owner approval is to be required in these activities

3. Thoroughly review the design standards that the contractor will use, and confirm that those standards will be used by subcontractors and all equipment suppliers as part of their bid packages
4. Come to an agreement on which responsibilities the contractor's construction group will assume in completing parts of the facility prior to turning them over to the owner, as well as which responsibilities the owner will assume. Frequently, the contractor has a list of contractor and owner responsibilities that the owner can review, or an industry standard can be used
5. Agree with the contractor on the timing for obtaining the environmental permits, what special provisions are needed for construction, commissioning and startup, and what impact permit timing will have on the overall project schedule
6. List all required permits and identify whether the contractor or the owner will have primary responsibility for ob-

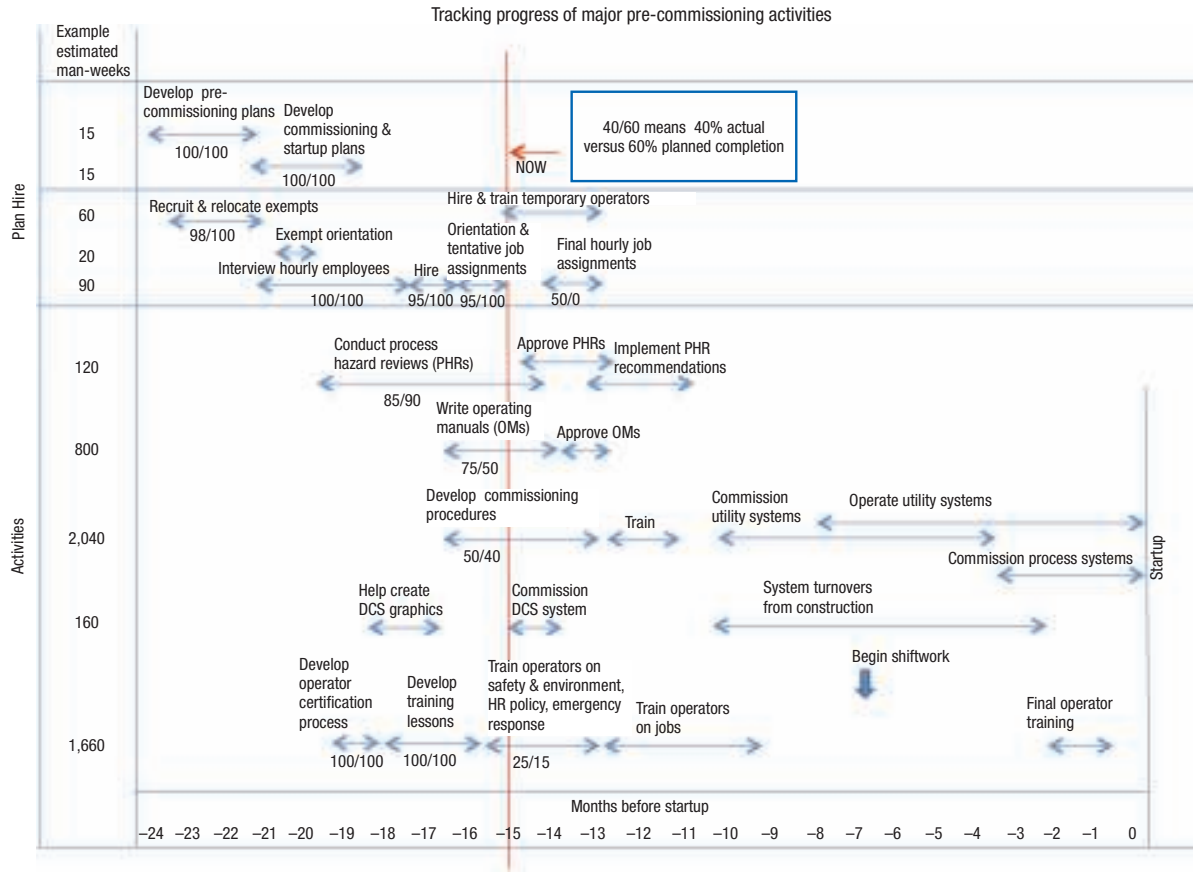
taining each. Although environmental permits are the major permitting issue, it is not unusual for construction of a new facility to require 20–30 other permits from regulatory agencies, some requiring many months to obtain. If any of these are not obtained in a timely manner, it can impact commissioning and startup

7. Specify in writing the extensive project documentation that the contractor is expected to provide from the contractor and the contractor's suppliers. The contractor should make delivery of supplier documents a condition of final payment in the purchasing terms and conditions with suppliers. Good documentation is imperative for efficiently accomplishing pre-commissioning activities
8. To the extent possible, the contractor and owner should align the contractor's construction areas with the planned commissioning systems so that construction turnover is done in a manner and sequence that supports timely commissioning
9. The owner's task force should work in conjunction with the contractor's construction group during the first few months of the project design to develop an agreed-to sequence and timing for system turnovers. This turnover schedule later forms the basis for a detailed commissioning schedule
10. Identify what assistance the contractor will provide during pre-commissioning, commissioning and startup, as well as a cost structure for that assistance. Also, identify where key supplier assistance is required, as some specialists require scheduling up to a year in advance

In summary, spending time on a project's front end can help ensure that the back-end efforts progress smoothly. These activities might include: analyzing the project's front end to make certain that sufficient owner-controlled funds are authorized; identifying for senior management what project staffing needs will ultimately be; specifying the owner's task-force involvement in design and procurement activities; and working with the contractor to clarify the responsibilities that will facilitate commissioning and startup.

Pre-commissioning activities

Pre-commissioning activities include all of the tasks that the owner's personnel must accomplish in preparing to commission, operate and maintain the facility. Beyond this, pre-commissioning also includes the development of processes and procedures that must be put into place to make each department a fully functional group. These departments may include operations, maintenance, process engineering, accounting, human resources, safety, environmental, pur-



Note: This chart is an example for the production department of a facility. Other departments, such as maintenance and process engineering, will require similar tracking charts for their different pre-commissioning tasks based on Table 2.

FIGURE 3. Tracking progress as startup approaches is crucial to avoiding project lag

chasing and logistics.

Some of these pre-commissioning activities involve interaction with the contractor, such as witnessing selected construction quality-assurance activities or accepting custody of equipment as construction is completed. Most activities, however, proceed independently of the contractor's work, including staffing the facility, setting up equipment spare parts, establishing logistics capabilities and developing procedures for operating, maintenance, human resources and cost accounting. Examples of departmental pre-commissioning responsibilities are shown in Table 2.

Obtaining adequate resources

The period between initial staffing of the site and initial shift operation of utilities is typically the most hectic, intense period in a project's cycle for plant personnel. An enormous amount of work must be accomplished.

The most important thing that a manager can do to ensure a project is well managed once pre-commissioning activities begin is to staff the project so that the large number of necessary tasks can be completed in the required timeframe. To do this, managers must identify the pre-commissioning activities well ahead of time, plan them in sufficient detail to estimate their manpower requirements, and then build the staff required to accomplish them in a timely manner.

For the support groups — those that will not be directly involved in commissioning work later — pre-commissioning activities can continue into the commissioning period. However, for personnel involved with production, maintenance, process engineering and process control, it is essential that their pre-commissioning activities be completed prior to the period when final operator job training and commissioning begin, as equipment is turned over from construction. Once this training begins, essentially all employees in these groups

will be fully committed to training, then to the formal process of accepting systems from construction, and then to commissioning these systems. If the bulk of the pre-commissioning work for these four groups is not completed prior to final training, they will be faced with unmanageable workloads and conflicting priorities.

The number of people necessary to accomplish all of the pre-commissioning work depends on more than the project's size. If the project is being integrated into an existing manufacturing site, fewer people will be needed in support organizations to develop processes and procedures than would be required for a new site. Just as important is the productivity of plant personnel. Supervision can enhance commissioning productivity by establishing a productive environment so that new hires have adequate work facilities. Also crucial is the provision of good orientation, resource materials, training and guidance on the requirements for their pre-commissioning tasks.

To accomplish pre-commissioning work within the timeframe set by construction, the level of staffing for supervisory, professional and hourly personnel will almost certainly need to peak above that which is required for the longterm, as seen in Figure 2. Frequently, temporary personnel, such as operators, mechanics, engineers, recruiters and accountants, are used to supplement resources to levels above those needed for later ongoing operations. These temporary personnel can be borrowed from other company facilities or hired from specialty contract firms. Even with this added staff, extremely long work-weeks are frequently the norm.

Pre-commissioning efforts at the site typically begin in earnest when the project design is about 40% complete.

Timing staff buildup

Pre-commissioning efforts at the site typically begin in earnest when the project design is about 40% complete. This is also roughly the same time that environmental permit approvals typically allow field construction to begin. Budgeting for sufficient staff when the project was authorized, as described earlier, will make timely staffing easier. However, authorizing staff does not necessarily mean that they will get into their intended positions in a timely manner.

The time required to fill permanent positions is usually about two months. Operator positions might need to be backfilled by a slow bidding process at an existing site, or by a hiring process that requires recruiting, interviewing and background checks. Professional personnel assigned to the project often need to undergo a lengthy process of being relieved from their existing assignments prior to relocating. Project taskforce members, who typically are destined to be key members of the facility's staff, may still have lingering obligations associated with the project design and procurement, such as witnessing equipment testing at vendor shops. These delays must be included in developing a pre-commissioning staffing schedule.

The commissioning of utility systems (electrical distribution, wastewater treatment, air and nitrogen distribution, freshwater treatment, steam and so on) progresses in a logical sequence that begins months ahead of the primary process systems. Therefore, staffing for utilities pre-commissioning activities, such as process-hazard reviews and training preparation, should also move forward to accommodate that timing.

Detailed plans and schedules

As mentioned previously, the workforce can be much more productive if supervisors plan

pre-commissioning activities well ahead of staffing the hourly positions. This enables all new hires to immediately begin working on specific tasks by being equipped with the tools and guidance necessary to progress efficiently. Some good examples of prudent early planning are as follows:

- List the training packages that must be developed with a tentative training schedule, including the following items: operator job training, mechanic training, regulatory-required safety and environmental training, human-relations policy training and so on
- Define the formatting and organizational structure for the content of the commissioning procedures, operating instructions, process hazard reviews and training segments. Also, develop training for personnel who will be creating these packages
- Identify and assemble the resource documents that employees will need in order to complete their pre-commissioning activities
- Identify the methodology to be used for each process hazard review. If software is to be used as an aid to expedite reviews, be sure to procure and install the software on computer systems well ahead of time
- Define the construction quality-control activities in which the owners' staff will participate, and develop the process for their participation
- Identify and install the information-technology (IT) systems that will be used for pre-commissioning
- Identify which parts of the process-control system (if any) are needed prior to the entire system being turned over from construction
- Develop job descriptions and criteria for hiring and relocating employees, as well as the methods for administering compensation and benefits. Develop training for people who will be interviewing job candidates
- Develop an orientation package for new hires that covers safety, process and cultural information
- Develop the necessary policies and procedures that will govern safety, environmental and human-resource practices
- Install adequate office facilities, including temporary facilities that are only required until permanent buildings are complete

As pre-commissioning plans develop, each activity should have a lead person assigned as being responsible for its completion. The degree of success in completing these activities may later form the basis for those employees' personal-performance assessments.

Monitoring progress

While the planning and scheduling of pre-commissioning activities should be done with a great attention to detail, monitoring of progress should not be so detailed that the focus on overall progress is lost. It is important to simply understand whether pre-commissioning activities are progressing at an overall satisfactory rate and which of the large-manpower activities may be lagging. One method of tracking progress is to employ a simplified "earned credit" system for major activities as milestones are accomplished. For smaller activities, departmental leaders may simply report an estimated percentage completion by talking to the individuals doing the work.

The effort on tasks tends to follow an 80%/20% rule — meaning that the majority of the effort (80%) will go into a few (20%) key activities. These are the activities for which monitoring progress closely is most important. A summary tracking system consisting of one page for each department's responsibilities, updated by departmental leaders twice monthly is typically sufficient. An example is shown in Figure 3. The progress of pre-commissioning activities should be communicated via a summary form throughout the organization as the project moves forward.

Culture and morale

Just as the construction group is building a new facility, the site's leadership is building a new organization. This requires a conscious effort if it is to be done successfully.

Employees come to a new site

with expectations based on the cultures at their previous workplaces. There may be an unresolved culture clash among employees if managers do not provide leadership in establishing the desired cultural elements for a new site.

The human-resources leader can promote the development of, and help all site functional groups establish, the cultural elements for the new site. Whatever cultural elements site managers elect to pursue, it is important that leaders consciously work to identify desired cultural aspects and model a culture of their own choosing, not have one evolve by default. This modeling often begins when personnel are relocated to their new site. Showing interest in and helping with personal issues associated with relocations gets families settled smoothly and allows employees to reach a productive stage more quickly. Furthermore, however, it can help establish a positive cultural foundation.

It is important that leaders consciously work to identify desired cultural aspects and model a culture of their own choosing, not have one evolve by default.

Also related to culture and relocation is morale. Maintaining high morale during these facility-preparation phases of a startup is often challenging. The enormous amount of work that must be accomplished by a newly assembled group of people during the pre-commissioning period tends to amplify the personal issues that arise from job changes, family relocations, new assignments, new working conditions and time constraints on task completions. These pressures all tend to increase collective angst. As part of establishing a productive environment, leaders must consciously work to identify and resolve significant employee-morale issues and shape the culture that will make the group a high-performance organization.

The management steps outlined in this article will help prepare organizations for a safe, successful commissioning and startup period that accomplishes business objectives. Adhering to the guidelines summarized below can help ensure timely, efficient startups for large CPI facilities:

- Prior to project approval, identify for the owner's senior management what financial and manpower resources will be needed to successfully execute the project
- Before contract award, determine the contractor's ability and willingness to provide the type of assistance needed for a successful commissioning and startup
- Focus the owner's task force on specific objectives during project design, and communicate these objectives to the contractor
- Identify pre-commissioning activities and secure an adequate staff for the tasks
- Identify "owners" for each pre-commissioning activity and track progress
- Early in the pre-commissioning period, develop requirements for the major tasks that are to be accomplished so that teams are following the same guidelines as they develop commissioning procedures, write operating manuals, conduct process hazard reviews, develop training modules and interview candidate employees
- Complete production, maintenance and process-engineering pre-commissioning activities before it is time to begin their efforts in commissioning
- Identify and pursue objectives that will help create the desired site culture
- Monitor and respond to people's needs and concerns. Address significant morale issues ■

Edited by Mary Page Bailey

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Connecting Operations Personnel to Reliability Efforts

Seven methodologies are described to help operations staff take greater ownership of asset performance

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The definition of ownership — to act as an owner — implies certain responsibilities. Consider the range of behaviors demonstrated by individuals when it comes to the automobiles they own. For some, car ownership leads to a relentless pursuit of caring for every aspect of the car, from operation to maintenance. For others, it is a daily wish that their cars will simply start when the ignition is engaged. The outcome of the diverse behaviors along this continuum of ownership will have a direct impact on the reliability, longevity and cost of ownership of these complex machines.

Throughout the chemical process industries (CPI), owners of complex, costly machines and systems (assets) tend to act along this same continuum. In general, CPI operators typically want to ensure the delivery of performance levels in terms of three important measures — reduced lifecycle costs, improved reliability, and increased longevity before replacement. However, different individuals will go about achieving these objectives in different ways. Within any CPI facility, the quest to ensure reliability is thought to require three partners — personnel from the operations, maintenance, and engineering Depts. All three sets of individuals play vital roles in helping the asset to meet its important objectives, via their interactions throughout the lifecycle of each asset.

The efforts of the engineering department should be building in reliability since the design itself has a greater impact on reliability compared to the efforts by maintenance and operations depts. combined. For many, maintenance department efforts are thought to be the primary element responsible for the reliability of the installed assets. However, from our knowledge of various paths for equipment failure (the majority of which are random in nature), it turns out that operations personnel hold the key to delivering optimal business objectives, through their efforts related to the ongoing operation of the assets.

To further explain this important concept, we must first understand the "bathtub curves," developed by Nolan and Heap in the 1960s and 1970s [*1*], which have driven maintenance practices in the airline industry for decades. The authors developed six failure curves that demonstrate how the probability of failure is a function of run time for machine components. The major finding was that 89% of these failure modes occur randomly — often with little to no warning.

At the time of these findings, industry's approach to maintaining industrial and other assets had been to rely heavily on preventive or time-based activities, such as planned overhauls. However, given that the majority of failures occur randomly, it is not practical to expect that a time-based approach to equipment maintenance will detect or identify all potential failures. While online monitoring options can provide a close proxy for realtime surveillance in some instances, we cannot place a mechanic at each machine to constantly monitor its condition on a real-time basis. The operations department is the only group with enough continual exposure to the assets on the plant floor to be able to detect the earliest signs of many impending failures. So why do many CPI facilities still experience relatively high levels of reactive or breakdown-related maintenance, and fail to effectively deploy their operational personnel to provide close ongoing surveillance of the assets in the field?

Operations ownership

In recent decades, there has been a transition in operations department culture. Many retirees lament the bygone era when operators knew not only how to operate their equipment

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but also understood how to maintain the function of all of the assets under their command. Historically, operators relied on using their four senses (hearing, seeing, touching and smelling) to keep close track of how the equipment was operating during their shift. They would adjust settings, add oil or grease, unplug and monitor their equipment and be able to detect small changes in the equipment condition and rapidly report their findings to the maintenance department Some even performed minor tasks to fix a problem early so as not to allow it to grow into a major downtime event.

However, more recently, that culture has slowly been replaced with a new mindset about the appropriate division of labor — that "operations personnel run the equipment" and "maintenance personnel fix the equipment."

Nonetheless, today, due to the complexities associated with maintaining complicated equipment and support systems, participation by both of these functions is essential. In some industries, operating personnel have become "more comfortable" with elaborate control systems and control rooms, which took the operator's exposure away from the equipment in the field. This drove an additional "wedge" into the culture of ownership needed to maintain equipment reliability. Now the question is, how do we return a state where operations personnel are once again empowered to be a critical partner — and allowed to take more of an ownership role — in the quest to maintain the asset base, as needed?

The path forward

Back in the 1950s and 1960s, management did not have to present much of a business case for operations personnel to perform all of the tasks that are required to maintain equipment. Operator rounds and minor maintenance were an accepted part of the job description. Today, owners must develop more of a business case to justify the use of operations personnel for such tasks, allowing them to act like the true owners of their equipment assets.

The path forward involves "selling" the benefits of more direct ownership by operations personnel. These include a more predictable and safer work environment for all personnel, improved business targets for cost savings, higher overall productivity (through reduced downtime and higher asset optimization), and the development of new skill sets for plant personnel.

TABLE 1. ALIGNMENT OF LEADING AND LAGGING METRICS AND MEETINGS

Frequency	Metric	Meeting
Daily	• Number of "bad actor" failure triggers (leading) • Number of critical-equipment failure triggers (leading) • Number of on-condition exceptions (leading) • Number of audit exceptions (leading)	Daily production meeting
Weekly	• Percent of preventive maintenance (PM) work completed (lagging) • Percent of predictive maintenance route completion (leading) • Pump repair-sheet compliance (leading) • Operator-driven reliability exceptions — no response • Number of breakdown work orders analyzed (leading) • Percent of proactive work completed (lagging) • Percent of proactive work scheduled (leading) • Number of machines that missed on-condition checks (leading)	Maintenance-scheduling meetings, production meetings
Monthly or Quarterly	• Downtime (lagging) • Pump MTBF (lagging) • Percent on-condition work orders created (leading) • Excessive work orders (rotating/electrical and Instrumentation) (lagging) • Mechanical Availability (lagging) • Pump failures (lagging) • Mechanical integrity inspections overdue (lagging) • Care plans created (leading) and implemented (lagging)	Reliability management meeting; Annual site strategy meeting

The business impact of these added operations department efforts should be demonstrated, by tracking metrics that are related to key business results. However, to be fair, the tracking should involve only business results that operations personnel could actually influence directly. Too often, management tries to translate the impact of operations department efforts using metrics that may be too strategic — such as mechanical availability and mean time between failures (MTBF) — and thus cannot be impacted easily by operations personnel actions. To be successful, this path forward also requires changing the mindset of company and plant managers, to establish metrics that really show the performance of operations personnel in the care of the equipment, and are thus attainable by operations personnel.

"Normalization of the abnormal" occurs when sub-optimal equipment conditions are tacitly accepted by those who operate the equipment. Left uncorrected, these sub-optimal conditions typically lead to reactive maintenance cultures, since the early signs of failure are not acknowledged and used to drive proactive repair. For instance, a valve that has "always been hard to close" is often taken for granted, until one day it does not close at all. Once the "new normal" state of equipment conditions are established (the valve is replaced), the early detection of potential failure modes can be recognized.

The importance of the need to recognize early signs of failure should be driven to the floor-level personnel, so they can quickly recognize failure and request repairs when they have the smallest impact on overall plant operation. This involves using periodic audits and basic troubleshooting tools, and providing accurate descriptions of what equipment requires repair. Operations personnel should be en-

couraged and allowed to return to performing basic and simple repairs (so-called autonomous maintenance). This approach will allow maintenance personnel to focus on performing proactive, strategic care tasks that are designed to move the facility away from reliance on reactive maintenance. In general, reactive maintenance often engenders higher costs, more downtime, and a workplace that is less safe overall.

Detailed below are several methodologies that can help drive a more-effective partnership between owners and the operations department Each of these is discussed in greater detail in the sections that follow: (1) Developing the value proposition; (2) Establishing metrics; (3) Changing the equipment-condition mindset; (4) Training and troubleshooting; (5) Integrating maintenance work processes; (6) Conducting operator rounds; and (7) Increasing autonomous maintenance. No single methodology will secure the role of the operations personnel as owners of the assets, but efforts to include operations personnel more completely in the care of the assets will eventually deliver the desired results.

1. Developing the value proposition. In general, a value proposition is a business or marketing statement that summarizes why an individual consumer should buy a product or use a service. This statement should convince a potential consumer that one particular product or service will add more value or solve a problem better, compared with similar offerings. The ideal value-proposition statement is short and appeals to the customer's strongest decision-making drivers. It is important to make sure operations personnel understand all of the reasons why they should take a more active role in equipment-care activities.

Management should first focus on "selling" operations personnel on the potential benefits of joining their colleagues in maintenance and engineering depts. in the pursuit of more reliable operations. Historically, management has told operations personnel that their primary job was to ensure that the manufacturing process is operated within the acceptable range of key operating variables — such as temperature, pressure and so on.

TABLE 2. LIST OF CONDITIONS TO BE RECOGNIZED DURING A RELIABILITY WALKTHROUGH

PRIORITY ONE WORK ORDER	
Leaks	Repair obvious leaks from pumps, seals, valves and utilities
	Address corrosion that indicates thinning and imminent failure
Environmental, health and safety (EHS) related	Address any condition that presents a potential EHS hazard
PRIORITY TWO WORK ORDER	
Condition monitoring	Any out-of-place heat, odor, noise and vibration
	Be sure that oil levels and automatic greasers are readable and have an appropriate date and level given their age in service
	Lubricate any rotating equipment that shows signs of not being recently oiled or greased
Field instrumentation and electrical conditions	Clean or replace dirty "non-readable" field instruments
	Ensure that instrumentation is indicating process conditions as specified (flows, transmitters and seal panels)
	Address leaks and disconnected lines and wires
	Ensure that cabinets and other housings should show adequate pressures and flows to meet area electrical classifications
	Repair electrical fittings, exposed wires, missing fittings and broken conduit, as needed
Housekeeping	Remediate obvious housekeeping issues
PRIORITY THREE WORK ORDER	
Visual factory	Replace any missing or damaged oil tags, vessel signs, hazard diamonds and reading indicators on critical gages
Insulation and scaffolding	Repair or replace any insulation that is missing or loose
	Address any scaffolding that is in need of repair or removal
Painting	Repaint any color-coded pipe that has become aged, per plant standards
Labeling and signage	Ensure that correct signage and line labeling is present per plant and unit standards
PRIORITY FOUR WORK ORDER	
Painting	Refresh aged paint on vessels and structures, per plant standards
Demolition	Remove unused, unrepairable or obsolete equipment

Historically, operations personnel have stressed that their first responsibility is to operate the process in a safe manner. They are also tasked with data recording and meeting responsibilities. One can argue that some of the data they are recording during operator rounds — for instance, "Is the pump running?" — are a form of "management control" and may not even be reviewed by supervisors. Some operators do not understand what the data tells them and they question why such data are being recorded at all. Based on this background, it is no wonder that for many operations personnel, equipment monitoring often takes "a back seat" to other responsibilities and they may not understand its full value in influencing asset reliability.

Appropriate monitoring of equipment and providing basic care does improve the operating environment for operators, and will help to achieve many safety, productivity, and cost goals that are established by management. In many facilities, operators are hoping for a predictable work shift, where the process is running at steady state with little variation and upsets. Processes that are not reliable tend to call for reactive maintenance, which contributes to unsafe behaviors. Thus, a useful value proposition for CPI operators may be expressed as follows: For operators of CPI assets who want to work in a safe and sustaining environment in order to provide for their families and loved ones, reliable operations require a day-to-day focus on reporting out-of-range conditions, recognizing the early signs of equipment failure, troubleshooting loss of function, recording required data, and looking out for each other's safety.

Management needs to reinforce that safety, sustainability and predictability are the strongest drivers in all

CPI operations. These words — and concepts — should be constantly reinforced at all levels of supervision, and should appear on information boards throughout the facility and be stressed at daily meetings. A small portion of the operations group will already understand the message, while another portion of the Operations group will require some evidence to get them involved.

2. Establishing metrics. The adage "What gets measured, gets improved" is heard throughout the business landscape. However, metrics can be a double-edged sword and sometimes individuals and groups can become bogged down by "paralysis by analysis" when excessive metrics are tracked, but for no clear purpose. Nonetheless, tracking of appropriate metrics can drive behaviors. People adjust their behaviors based on what aspects of their performance are being measured. For instance, if plant personnel are evaluated for process uptime alone, they may not make the best decisions about how they operate the equipment.

Tracking the right combination of metrics can propel an organization toward desired targets for improvement, while focusing on the "wrong" mix can steer people toward contradictory actions and may lead to more inefficiency in terms of wasted costs or time. The "right" mix of metrics includes both "leading metrics," which measure process activity such as the amount of practive work scheduled, and "lagging" metrics, such as maintenance-schedule compliance and mechanical available, which measure an outcome.

In general, lagging metrics are more strategic, and thus management tends to put disproportionate emphasis on them. However, operators are often not able to meaningfully impact these metrics. For instance, in the case of reliability, focusing on MTBF with maintenance and operations personnel generally draws blank stares. However, directing their attention to leading metrics, such as percent of work orders with work history, percent of scheduled lubrication routes completed, and percent of exception found on equipment monitoring routes, allows them to "move the needle" on plant operations that will eventually impact MTBF. Table 1 illustrates this concept further.

TABLE 3. SAMPLE WORKSHEET TO PRODUCE A "FIVE WHY" REPORT

Equipment location		First floor
Equipment description		Process pump
Failed component		Impeller and valve
Date of event and time		2/4/15 second shift
Name (Leading the discussion)		T. Jones
Names (Participating)		Various
1. Failure description – What happened?		The pump was making a loud noise.
2. Why did it happen?		Cavitation is occurring.
3. Why did it happen?		Flow conditions changed.
4. Why did it happen?		The inlet to the pump was plugged.
5. Why did it happen?		The inlet valve upstream failed.
Root-cause statement: The impeller failed from cavitation that occurred as a result of changing flow conditions.		
Major corrective action: How can this be prevented? Where else does this apply? Ensure that valves upstream of the pump are tested for proper operation.		
Actions and responsibilities: Maintenance will change the valve and replace the pump impeller.		
Action:	Who:	Date:
Action	Who	Date

Table 1 also shows the timing of reporting leading and lagging metrics. Leading metrics should be discussed daily to weekly, whereas lagging metrics should be discussed weekly, monthly and quarterly, because the ability to change lagging metrics generally takes more time. Operations and maintenance personnel can become frustrated when seeing little movement in lagging metrics, when their focus should really be on "moving the needle" with those metrics they can impact directly over shorter time horizons.

3. Changing the equipment-condition mindset. As noted, "normalization of the abnormal" is the enemy of reliable operations over the long run. The acceptance of suboptimal existing conditions, such as loose fittings, small leaks, tough-to-close valves, and many others represent the waiting room for failure. Unfortunately, these conditions become part of the landscape in many manufacturing facilities, and with the existence of higher-priority reactive work, they often never get fixed.

Operations personnel are exposed to these conditions on every shift. They often bring attention to these issues but get little response. When this pattern persists at a facility, it is difficult to recruit operators as partners in the pursuit of improved reliability, because they can point to many examples that indicate that management is not willing to fix items they report. The path forward is for management to demonstrate its commitment to remediating these early signs of failure, as a proven way to forestall larger problems later.

One useful method to deploy is the reliability walkthrough. Just as many manufacturing operations perform safety walkthroughs of their units, another set of audits should be performed to monitor equipment condition. Plenty of preparatory work is required before starting. The first step is to gain buy-in with production management to perform these audits. Such buy-in can be gained by showing existing field evidence of conditions that require repairs, such as missing conduit covers, bad valves and missing oil containers. Recognizing a prevailing lack of attention toward equipment is vital to encourage a change in attitude. Leveraging management's commitment to improving reliability is another.

Once buy-in is achieved, the maintenance and reliability departments need to set up a standard for what conditions are considered abnormal, and make it a priority to fix these conditions in accordance with the existing maintenance execution process (Table 2).

Next, establish a schedule for these audits. Participation should include Production management, op-

erators, maintenance or reliability engineers and maintenance personnel. One attendee is assigned to be the scribe to record what is found and set the priorities for the work.

After the audit, the list is converted to work-order requests. These audits should be more than just a "fix-it" tour. They should represent a culture-changing event so that over several months of audits, operations personnel will begin to better understand what represents acceptable equipment conditions. They begin to see management's commitment to improved reliability and safety. Eventually (after a year or so), a variety of metrics are used to show progress.

Relevant metrics include percent reactive work, percent mechanical availability, percent process uptime and MTBF. Consistent effort will generally show improvement across all classes of assets, especially when participants demonstrate patience, commitment and consistency. Consistency is important — plant personnel must avoid the temptation to postpone audits due to other demands or priorities, attendance issues, weather, and downtime.

4. Training and troubleshooting. Operator training is often restricted to safety and process-operations-related areas. For operators to progress to increased levels of responsibility, they generally focus on improving their breadth of unit knowledge, achieving better process understanding and developing increased analytical capabilities. However, often left out of the training is attaining improved understanding of equipment operation. Also, understanding the principles related to pressure, temperature and flow measurement may not be part of their training matrix. And yet insufficient training in these topics can lead to failure in CPI operations. The majority of failures in the manufacturing environment result from how the equipment is operated. Examples include improper pump operation, running equipment outside of design limits, improper setup, lack of lubrication and missing needed adjustments, to name a few.

A lack of understanding of machine operation is another hurdle facing operations personnel. For operators to partner effectively with maintenance and engineering personnel, the first steps are to determine the gaps in their understanding of equipment operation, and related principles of pressure, temperature and flow. Any identified gaps should be included in the training matrix that is required for operator responsibility progression. Trainers may come from in-house engineers, maintenance personnel, training professionals, third-party vendors and even local colleges.

TABLE 4: OPERATOR ROUND CHECKLIST

- ✓ Focus on quality, cost, safety, environmental and productivity data
- ✓ Ensure the data you collect or the tasks you ask your operators to perform add true value to your business – focus on critical assets
- ✓ Minimize travel and enable remote monitoring
- ✓ Include expected ranges and support with visual techniques
- ✓ Provide feedback systems so personnel know the work they are performing means something
- ✓ Set up clear responsibility and accountability
- ✓ Enable data gathering with simple tools
- ✓ Train people to do inspections and gather data properly
- ✓ Include troubleshooting steps if variations are found
- ✓ Manually record data first, automate the recording of data second
- ✓ Convert manual recording to the use of electronic handheld devices (10% productivity improvement)

During training, the topic of troubleshooting deserves special attention. The aim is to drive troubleshooting to the floor level, so that problems can be solved quickly and avoid involvement from the maintenance department Such an approach benefits both maintenance and operations efforts. Operators should be required to perform basic troubleshooting from the first signs of variance from normal operations. One easy tool to use is a "Five Why" structure (Table 3). It requires the participant to question each observed result by asking "Why?" five times to drill down on the events that occurred, in order to identify a root cause.

Although the "Five Why" approach is limited in its application, it does apply to many situations faced by operations personnel. Oftentimes, operations personnel can resolve the issue themselves before calling their colleagues in maintenance. Even if they cannot resolve the issue, the information derived from the initial investigation and troubleshooting efforts will improve the content of work order requests, which will help maintenance personnel to be more efficient. Operations personnel should also be included as part of more formal root-cause investigations, as a participant, so they can contribute needed information.

5. Integrating maintenance work processes. A partnership is built on eliminating boundaries. Many manufacturing locations restrict operations department access to their computerized maintenance management system (CMMS). This barrier prevents operations personnel from executing their role in equipment care, potentially creating restrictions in submitting work requests. At some locations, operations personnel must contact a maintenance representative or a supervisor to submit work requests. This added step can restrict which needed work is performed.

In general, operations personnel should be given limited access to the CMMS. For example, operators should be able to submit work requests at any time. The maintenance department gatekeeper on the CMMS system will ultimately decide the priority of all submitted work requests. The site can set up a few logon identifications and terminals for access and provide operations personnel with access to view work orders and their status.

The quickest way to frustrate any initiative by operations personnel who are willing to participate in the care of the equipment is to not provide feedback to the suggestions they make. Giving operations personnel access to the CMMS will allow them to view and track the status of audit findings and other submitted work orders and suggestions they may submit.

The maintenance department also has a role to play in this partnership when it comes to work-order execution. For instance, work-order schedules should be distributed to operations personnel so they can prepare for the work to be performed. Priorities should reflect the current state of the operation department priorities. After responding to a work order,

maintenance personnel should seek out the specific operations personnel with the work-order response to acknowledge their submission and ensure their satisfaction with the work and the condition of the area after the work was performed.

6. Performing equipment rounds. A widely held belief in industry is hat "Operators can fail the best designed equipment, but they can also run marginal equipment."

Some equipment-round sheets are no more than checklists and contain no standards to help personnel recognize abnormal operating conditions. Data are typically gathered by operators with little understanding of why it is important to the operations of the process. Periodic equipment rounds in some cases represent a form of "control" designed by supervision to keep people moving. Given this landscape, operators tend to "pencil-whip" (give a cursory effort but not complete) rounds as they may not understand their purpose.

To make equipment rounds most effective, operations personnel should always start with a focus on the critical assets (at least at the beginning), rather than all assets, to make best use of the time.

Useful data to be gathered in the field should indicate the "health" of the assets. The use of visual techniques will allow an individual to understand quickly if many types of equipment are operating normally. For example, note the expected range on a pressure gage and mark on the operator-rounds sheet whether that gage is operating within the target range. Ensure that someone is reviewing the operator-rounds sheets (or their equivalent in an electronic database) and that feedback is given when variances are observed. Table 4 provides a brief checklist that can be used during operator rounds so their efforts align with the recommendations discussed above.

7. Autonomous maintenance. The early detection of failures benefits chemical process operations through greater uptime, reduced maintenance costs and a safer working environment. As operators are closest to the daily operation of mechanical assets in a CPI facility, increased operator awareness and involvement in all reliability efforts is a key enabler to this early defense warning system for impending functional failure. Constant monitoring by these strategic personnel provides an opportunity to correct a variance before it has a chance to affect overall plant operations.

Even more advantageous to the facility is when relatively easy repairs can be made on the spot (involving such rudimentary tasks as tightening flanges, replacing packing and so on), rather than requesting maintenance department involvement and then awaiting their arrival. The time lost waiting for repairs can increase the cost of the repair and take maintenance personnel away from other proactive tasks that are needed to provide asset care.

Encouraging autonomous maintenance activities for certain tasks by

TABLE 5. OPERATOR-DRIVEN RELIABILITY ACTIVITIES		
Level one: Standard operations — Non-contact, troubleshooting	**Level two: Operator-involved maintenance — Inspection and monitoring (Non-contact)**	**Level three: Operator-performed maintenance — Autonomous maintenance**
• Startup, operations, changeover, adjustment, shutdown • Use human senses • Address source of leaks, dirt, grease other problems • Raise awareness of "bad actors" • Change procedures and carry out training • Carry out routine housekeeping and cleaning • Change filters • Clear plugged pump suction	• Walkarounds • PM inspections (including checking oil and lube levels) • Manage lubrication closely • Low-tech condition monitoring (using strobe light, stethoscope, vibration pens, IR temperature) • Monitor critical process variables • Bearings and motor temperature • Inspect couplings • Inspect belts and sheaves • Inspect chains and sprockets • Check ultrasonic leaks	• Tighten bolts, adjust belts and tighten valve packings • Change light bulbs and other indicator lights • Install flange blinds • Assist in maintenance • Adjust and calibrate • Replace filters and other consumables • Fix leaks • Perform failure analysis

operators offers one solution. Unfortunately, industry's history with utilizing operators for these tasks has not always yielded a success story. Site-specific work rules, lack of training, lack of a value proposition, and "perhaps exaggerated" concerns for safety tend to keep operators from being allowed to handle these important tasks.

However, with strong management support, these obstacles can be — and have been — overcome at many CPI locations. First, a policy is needed to indicate which elements of corrective (autonomous), preventative and predictive care can be performed by operators, and then to establish buy-in among all affected parties. Maintenance personnel can be assured that operators are not trying to replace them. Staff support is needed to convert the appropriate preventive maintenance tasks to condition-based tasks for operators to perform. In fact, roughly 30% of preventive maintenance tasks can be done by operators. Table 5 summarizes the important steps that are needed to establish a multistep approach — one that recognizes three levels of possible operator-driven reliability activities.

The selection of which of these levels to perform will be a function of site needs, culture and operator skill level. As indicated in Table 5, operators in level one perform normal operating tasks along with non-contact tasks involving the four senses (hearing, seeing, touching and smelling). Of course touching can be done with limitations. In addition, the Level one group includes executing simple tasks, such as setup, cleanup, adjustment, alignment and checking that are required to ensure proper asset operation.

Level two tasks attempt to use operators for some condition-based tasks, including the use of some non-contact tools to diagnose asset condition. Lubrication is included in this level and will require the setup of a lubrication program (consisting of minimal selection of lubricants, establishing color-coded lubrication locations, establishing lubrication storage, and developing checklists that direct appropriate lubrication protocols). Performance of level two tasks does not require mechanical skills, perhaps just some rudimentary training.

Level three moves closer to the definition of autonomous maintenance, with operations personnel carrying out some basic care tasks, using a few select tools. What is important in this level is the inclusion of the expectation that the operations personnel will assist with the troubleshooting of equipment failures. Maintenance personnel will eventually come to view the assistance from operations personnel as a benefit to the overall mission of the facility; which is to maintain and restore safe, reliable function. In facilities that have adopted this approach, the maintenance department often remarks that consistency in the way in which the equipment is operated, monitored and maintained provides great benefits.

Closing thoughts

Success in achieving site reliability is based upon the "triad" that is formed by a solid partnership between operations, maintenance, and engineering personnel, all performing their respective roles in applying the "right" practices throughout the life of all plant assets. No successful reliability effort can be accomplished without all three groups "pulling their weight." Unfortunately, cultural norms within CPI operations often do not allow all parties to participate fully.

In particular, operations personnel often consider that their role is to "run" the equipment while maintenance personnel repair it upon failure. Nonetheless, operations personnel have the most direct and consistent exposure to the equipment over time, which gives them invaluable access to detect the early signs of potential failure. Thus, they can play a critical role in reducing machine failures. Each of the seven methodologies discussed here provides essential elements to help drive an operational excellence program, and promote greater cooperation among the three groups in the triad, in order to maximize safety and process uptimes while lowering operating costs. ■

Edited by Suzanne Shelley

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Flare-Gas Recovery Methods for Olefin Plants

Adding flare-gas recovery units at strategic locations of an olefin plant can not only reduces emissions, but will save money as well

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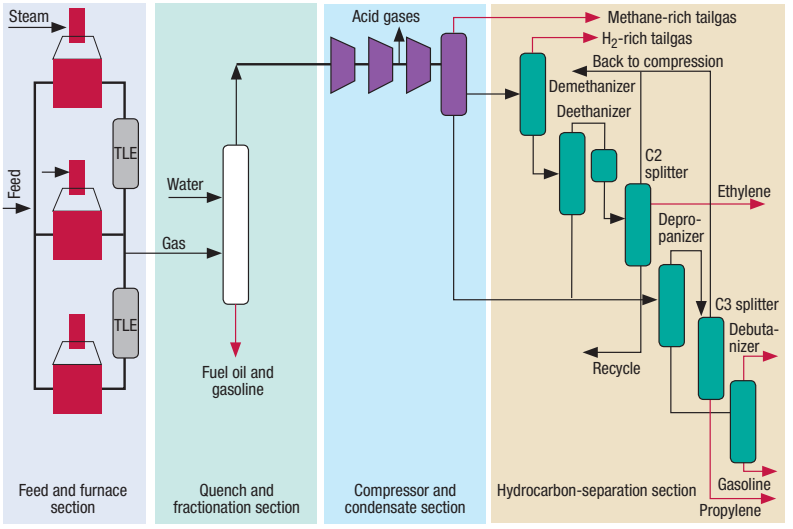
Although gas flaring is necessary at some chemical process industries (CPI) plants or facilities, more and more efforts are underway to reduce flaring, not only to help reduce emissions of air pollutants, noise and light, but also to save both energy and raw materials, which translates into money — potentially millions of dollars.

Today, plant operators are becoming more conscientious about reducing the release of greenhouse gases (GHGs), especially carbon dioxide, in an attempt to prevent further global warming. In some countries, existing or pending regulations on the release of GHGs, or the imposition of carbon taxes are forcing operators to rethink the simple option of gas flaring.

In some cases, however, it can make good economic sense to recover rather than burn the flare gases, which are often valuable hydrocarbons that can be used as fuel or even feedstock. The investment costs for adding a flare-gas recovery unit (FGRU) can thus be offset by utilizing the energy or the resources (or both) recovered by the FGRU. The environment benefits by reducing the volume of flare gases that are actually flared.

In this article, we investigate methods to recover flare gases and thus reduce gas flaring in olefin plants. As an example, the benefits of installing an FGRU after the cold flare drum at an ethylene plant are presented.

The article examines flare-gas recovery methods and the advantages of applying them to olefin plants. The case study presented here concludes that significant amounts of ethylene and fuel gas can be recovered, with corresponding savings of more than a million dollars per hour.



TLE = Transfer line exchange

FIGURE 1. A typical flowsheet for an ethylene plant is shown here [*1*]

Olefin plants

Olefin units (Figure 1) are among the most profitable plants in the petrochemicals industry. Due to the nature of these units, there is a good potential for using FGRUs during startups to reduce emissions and recover capital. Given the expanding number of olefin units in the world today, with flaring an integral part of the factories, large amounts of energy and capital are lost. Therefore, it makes good sense to consider more deeply the use of FGRUs with such units.

Flares and flaring

Flaring is a safe and effective method for the disposal of hydrocarbons in situations where there is an equipment failure or in emergencies, such as instrument failure, power failure or a fire in the plant. Many vapors are corrosive, explosive or flammable and cannot simply be released into the atmlosphere, so burning them is essential [*2–4*].

Flares are classified according to different viewpoints, for example in terms of the following:

- *Height* — elevated (according to the support, which can be self supported, guyed wire, derrick) and ground flares
- *Assisted fluid for smokeless operation* — steam-assisted or air-assisted flares
- *Combustion chamber* — open, semi-open or closed flares
- *Number of tips* — multipoint or matrix flares
- *Flare-gas pressure* — high-, medium- or low-pressure flares
- *Special areas* — storage areas or terminals can have dedicated flares

Flaring points in olefin plants

To achieve zero flaring, we must first investigate what are the main reasons for flaring. Activities where flaring is used include plant startups and shutdowns, maintenance procedures, plant upsets and sometimes even normal operation.

Flaring leads to the release of large

amounts of CO_2, carbon monoxide, oxides of nitrogen (NOx), hydrocarbons and other volatile organic compounds (VOCs) and others. Besides emissions to the atmosphere, simple flaring is a loss of both energy and raw materials.

For instance, an ethylene plant with a production capacity of 1.2 billion lb/yr of ethylene can easily flare about 5 million lb of ethylene during a single startup. Assuming a flaring efficiency of 98%, the resulting air emissions will include at least 15.4 million lb of CO_2, 40,000 lb CO, 7,400 lb NOx, 15,100 lb of hydrocarbons and 100,000 lb of VOCs. This is just a normal accounting of ethylene flaring emissions. If all the flaring sources are included, such as ethane, propylene and propane, huge amounts of air emissions can be produced through one single plant startup. By reducing the volume of flare gases, we can also be assured of complete combustion and a smokeless flare.

The main activities at olefin plants that lead to gas flaring are from the following sources:

1. *Cracked-gas-compressor (CGC) suction:* When the compressor is stopped; from the initial startup of furnaces until the furnaces reach their full capacity; and during the commissioning of the compressor
2. *Chilling train tailgas outlet:* When there is a limitation to the fuel-gas system from the demethanizer, additional products will be sent to the flare for plant-safety considerations
3. Deethanizer *top product:* When this stream is not within design specifications for sending to the hydrogenation reactor, there will be flaring in order to prevent catalyst deactivation
4. *Hydrogenation reactor outlet:* A large amount of flaring in an olefin plant occurs at this point. The outlet stream from the reactor will be sent to the flare until the required specifications are achieved. There will also be gas flaring after sending this stream to the C2-splitter tower until the tower reaches the normal operation conditions and liquefaction occurs
5. *C2-splitter top stream:* Until the tower product reaches the required specifications, there will be gas flaring

Flaring may be scheduled or unscheduled. Unscheduled flaring may be caused by a trip. Scheduled (or planned) flaring occurs during shutdowns, maintenance and startups. During a shutdown, the plant feed will usually be decreased to the minimum amount with which the plant is still stable, and the cracking-gas compressor will be out of service. This process will lead to flaring.

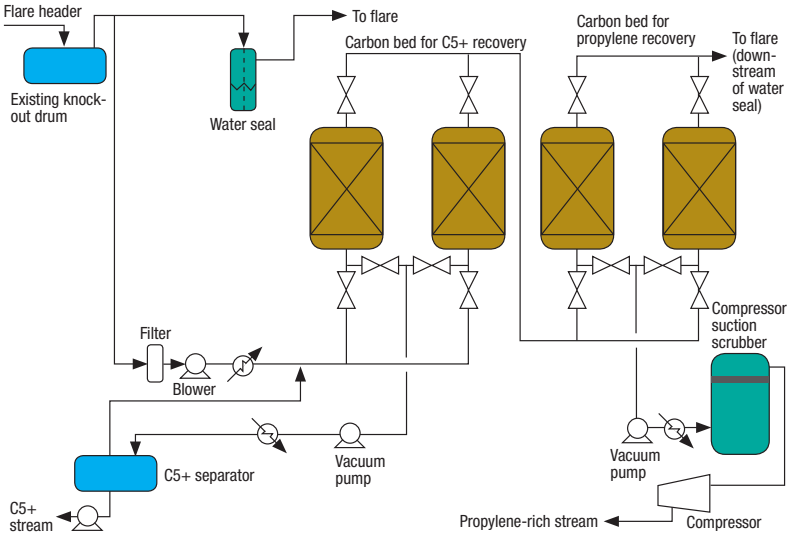


FIGURE 2. This flare-gas recovery system is based on beds of activated carbon [*8*]

Startup is a situation that leads from the initial state of the process to the final operating conditions. During this operation, the feed is gradually increased and equipment will be pressurized, and hot or cold liquids will reach their operating conditions. During these activities, large amounts of gas are directed toward a flare boom.

Unscheduled flaring includes operation failures, equipment failures, electrical failures and so on. When such events occur, the best option to ensure the safety of equipment and personnel is flaring, which is an effective, safe and fast method for handling gases that are generated. For plant trips that lead the unit into a purge condition, activities must be quick and effective to return the unit to normal operating conditions.

Most trips occur with cracked-gas compressors, refrigeration cycle compressors, instrument failure, weather and so on. These trips may cause a partial or total shutdown of a plant. In such circumstances, pipes and equipment are depressurized and the vent streams are sent to the flare until the unit can be returned to normal operating conditions.

We can summarize the following methods that can be used in reducing gas flaring in ethylene plants:

1. Define recycle streams for the recovery of off-specification products
2. Maintain the amounts in towers by keeping them in total reflux status
3. Properly control feed when injecting feed into furnaces, one furnace after another
4. Cool the chilling section as quickly as possible to reach the optimum temperatures
5. Ensure that conditions are normal before the demethanizer flow is established downstream
6. Return high-purity ethylene back into the reflux drum to reduce the settling time in the tower [*5–7*]

Ethylene plant FGRUs

There are several methods for flare gas recovery, which include the following general categories:

1. *Physical:* The gases are recovered and purified by special equipment and pressurized (if required) for process units to be used as fuel or feedstock
2. *Chemical:* The flare gases are reacted over a catalyst and converted into industrial materials that can be recovered
3. *Biochemical:* This newest method of recovery is performed using bacteria that carry out degradation reactions in the towers, thereby converting the flare gases into

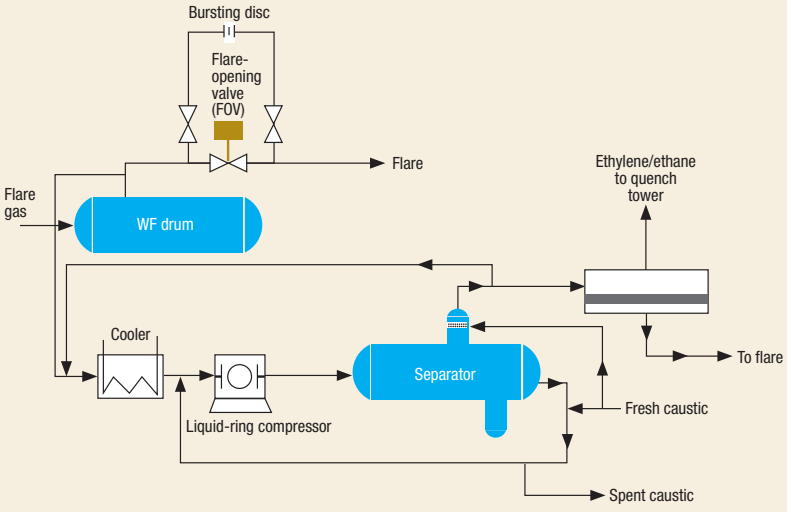


FIGURE 3. This proposed FGRU can be used on the outlet of the wet flare drum to return C2 components to the quench tower

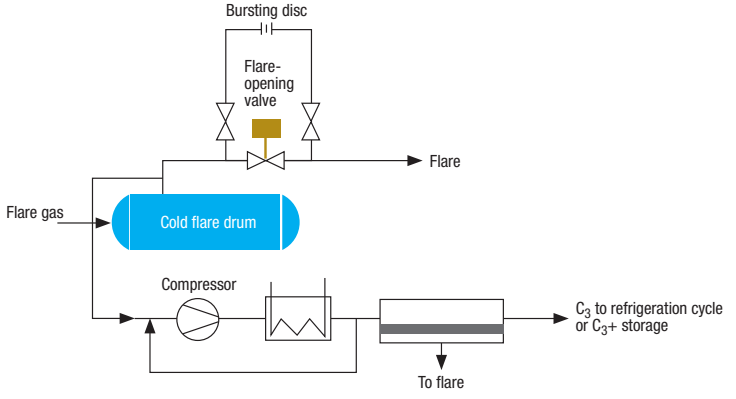


FIGURE 4. This proposed FRGU can be used on the outlet from the dry and cold flare drum for the recovery of C3 components

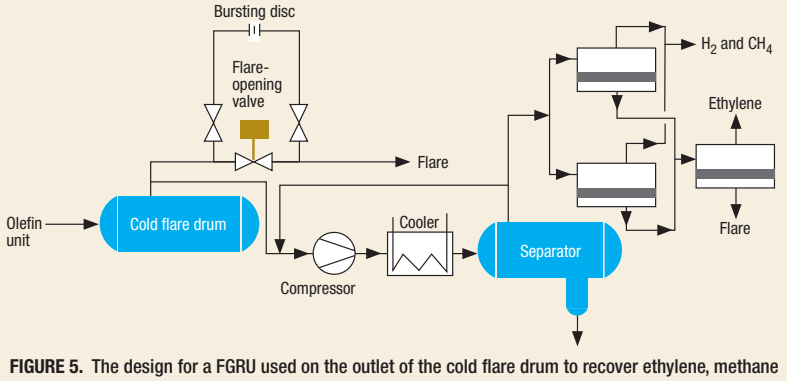


FIGURE 5. The design for a FGRU used on the outlet of the cold flare drum to recover ethylene, methane and fuel gas

simpler components

Regardless of which method is used, the recovery of some or all of the flare gases will decrease combustion products and the release of pollutants into the atmosphere, reduce fuel requirements and minimize flare-tip maintenance, as well as reduce thermal radiation, light, noise and odor. Ultimately, flare-gas recovery leads to increased plant efficiency.

In order to select the most appropriate solution for flare-gas recovery and the reduction of gas flaring, you must have a good understanding of how the flare gases are produced, distributed and best consumed at the production facility.

Designing an FGRU for an ethylene plant is far more complex than designing one for a liquified natural gas (LNG) plant or for petroleum refineries, because the processes and equipment performance at an ethylene plant are highly sensitive to the compositions involved. For example, changes in the heating value of fuel gas fed to the furnace can cause the destruction of the special burners. Composition changes can even cause problems in the pyrolysis process, resulting in a plant shutdown. Therefore, when introducing flare-gas recovery in ethylene plants, one must be very careful to keep the operation of the plant stable and ordered.

There are two physical-separation processes that can be used in olefin FGRUs: membrane separation and adsorption. It should be noted that the use of temperature-swing adsorption (TSA) greatly increases the risk of undesirable olefin polymerization reactions; but with pressure-swing adsorption (PSA), such risks can be avoided.

Figure 2 shows an example of an adsorbent system based on activated carbon (AC) for flare-gas recovery. There, one can see that a stream from the main header from the knockout (KO) drum is directed to the FGRU. This stream is directed to a blower and sent to the absorber system. (The blower prevents any problems that might occur in the flare-gas header).

The first pair of AC beds are for C5+ recovery and second pair for propylene recovery. The stream leaving the top of the propylene adsorption beds is rich in nitrogen, and is sent to a flare downstream of the KO drum [*3, 8*].

In addition to adsorption beds (including PSA), membrane-based separation systems can be used for the recovery of propane/propylene and ethylene at the refrigeration cycles charge, with the remaining gases sent to the C3+ storage tank. It is notable that the recovery and reuse of valuable components, such as C2 or C1–C3, from the wet flare (WF) drum to the quench tower is possible and economical (Figure 3). This should be kept in mind during the

TABLE 1. EMISSIONS FROM FLARING

Pollutant	Without FGRU (lb/h)	With FGRU (lb/h)
NOx	9.90	6.65
CO	71.42	48.01
CO_2	75.50	50.76

initial design stage for a new plant, so that the design of the refrigeration cycle can include enough cooling to supply the FGRU. In this way, we can recover valuable gases and reduce emissions form gas flaring.

Generally, all of the quench towers in an olefin plant operate in the pressure range of 0.4–0.5 barg. Because caustic is available both for cooling and as the absorbing media, it can be used for operating the liquid-ring compressor in Figure 3.

Additional methods are possible for recovering flare gases from the cold flare drum, as shown in Figures 4 and 5. In these methods, the outlet gas from the cold flare drum are sent to the FGRU using one compressor. Because the gas in this section (cold section) is dry, it is not necessary to use a special compressor, such as a liquid-ring compressor. Another important advantage is that an absorption tower (and regeneration of the absorbing fluid, if using amines) is not required.

Parameters affecting FGRU

The parameters with the strongest influence on the recovery system is the composition of the flare gas. In general, changes in molecular weight in the stream going to the FGRU can create the potential for overloading the compressor, leading to possible damage. Molecular weight changes can also increase the temperature of the gas after compression. The following three compositions have the most notable influence:

1. The effect of N_2 on heat exchangers and compressor performance
2. The effect of H_2 and light gas on compressor performance
3. The effect of steam on the separation drum, the compressor and membranes

The temperature of the inlet to the compressor must also be controlled. If the compressor inlet temperature is higher than the design temperature, the gas must be diverted to the flare. It should be pointed out that the capacity of the FGRU is a function of the capacity of the compressor system that is used [*9, 10*].

TABLE 2. EMISSIONS FROM FLARING

	Thermal radiation (kW/m^2)		Noise level (dB)	
Distance (m)	Without FGRU	With FGRU	Without FGRU	With FGRU
10	5.66	3.46	86.30	85.00
20	5.87	3.44	86.19	84.89
30	6.04	3.40	86.02	84.72
40	6.14	3.32	85.78	84.49
50	6.17	3.23	85.50	84.21
60	6.14	3.12	85.18	83.89
70	6.04	2.99	84.83	83.54
80	5.88	2.85	84.46	83.17
90	5.67	2.71	84.08	82.78
100	5.42	2.56	83.68	82.39

Emissions from flaring

In order to compare the emissions of pollutants, noise (acoustical) and thermal radiation for a plant before and after the introduction of a FGRU, one must first be able to calculate these values for the case of flaring only. Simulations were performed using commercial software for a typically sized olefin plant with a flare gas capacity of 90 metric tons per hour (m.t./h), and the results were compared to the same plant that uses the third proposed FGRU shown in Figure 5. The 90-m.t./h value is typical for the startup of an olefin unit that had been shutdown due to a problem in the cold section. The calculations for the simulaton were based on the following equations:

Pollution emissions. In the high-temperature combustion processes, several hundred to several thousand chemical reactions are taking place. Assuming complete combustion, the following general reaction can be used:

$$C_xH_yS_zO_w + \left(x+\frac{y}{4}+z-w\right)O_2 + \left(\frac{0.79}{0.21}\right)\left(x+\frac{y}{4}+z-\frac{w}{2}\right)N_2 \rightarrow xCO_2 + \frac{y}{2}H_2O + zSO_2 + \left(\frac{0.79}{0.21}\right)\left(x+\frac{y}{2}+z-w\right)N_2 \quad (1)$$

Of course, complete combustion is not normally achieved in flares, so there will also be carbon monoxide, NOx and other hydrocarbons released during flaring. A simpler way to calculate the effluent of pollutants during flaring is to use Equations (2):

$$E_x = QEF_x \quad (2)$$

Where:

Q = *production rate*

E_X = emissions of pollutant x, lb/h

EF_X = emission factor of x (from the the U.S. Environmental Protection Agency's compilation of emission factors, AP-42 [*11*]

Table 1 shows the results of the calculation for the emissions of NOx, CO and CO_2 before and after the installation of a FGRU.

Noise and radiation. The thermal radiation and noise level as a function of distance from the flare can be calculated using commercial software for flare systems. The results of these calculations are presented in Table 2.

It is also possible to make quick estimates of the thermal radiation released during flaring of gases by using Equation (3):

$$Q = VH \quad (3)$$

Where:

Q = production rate

H = heating value

V = volume of gas

A simple calculation for noise emissions can also be performed using Equation (4), which is based on the VDI 3732 Guidelines for an elevated flare [*12*]:

$$L_{WA} = 112 + 17\log\left(\frac{q}{q_0}\right) \quad (4)$$

Where

L_{WA} = weighted average sound power of the total noise emitted, dB

q = gas mass flowrate, ton/h

q_0 = reference mass flowrate, ton/h

For a flare that burns a gas stream of 90 m.t./h with a heat of combustion of 2,390 kJ/kg, Equations (3)

and (4) give 59,800 kJ/s or about 60 MW of power released by the flare. This value drops to about 40 MW with the introduction of a FGRU that reduces the volume of gas flared by about 40% (35.9 m.t./h).

For the same 40% reduction in flare gas being flared, Equation (4) shows a reduction in sound emissions by about 6.8 dB.

Payback

Table 3 shows that the total investment costs for the FGRU proposed in Figure 5, which is capable of handling a flare-gas stream of 90 m.t./h, is about $30 million [*13, 14*].

Based on the installation of such a FGRU after the cold flare drum, we have calculated that 43.3 m.t./h of ethylene and 10.8 m.t./h of fuel gas can be recovered and returned to the olefin plant. The value of the recovered gases is roughly equivalent to about $52,000/h.

According to monitoring studies, this olefin plant has about 185 hours of flaring per year during planned or unplanned shutdowns. This means that about $9 million/yr of valuable gases are returned to the plant and the investment costs are recovered after about three years of operation of the FGRU. The environmental benefits of reduced emissions of pollutants, noise and thermal radiation are an added bonus. ■

Edited by Gerald Ondrey

TABLE 3. INVESTMENT COSTS FOR ONE ETHYLENE-PLANT FGRU

Cost	Item
$16,900,000	Equipment
$3,890,000	Instrumentation
$997,000	Piping
$797,000	Electrical
$5,980,000	Operation
$26,300	Construction and installation
$29,800,000	Total

Acknowledgment

The authors would like to thank Najem Beg and Sacha Sarshar from Caltec Co., and Gholamreza Jokar and Shapour Taghipour from Morvarid Petrochemical Plant for their support and guidance.

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Troubleshooting Tube-Deterioration Mechanisms in Direct-Fired Heaters

A practical step-by-step guide for reducing tube failures

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Forced outage of a direct-fired heater is the worst nightmare for any operator in a petroleum-refining or petrochemical plant. Since fired heaters are not replaceable by spares, forced outage in many cases means emergency shutdown of the entire plant. In most cases, actual tube failure or even severe tube deterioration are responsible for outage of a direct-fired heater. Tube-deterioration mechanisms are not only an economical concern, but also a matter of safety for the plant and personnel. An unpredicted tube rupture may lead to disastrous explosions and severe human casualties.

In order to prevent such unwanted events and keep the fired heater tubes functional as long as possible, many petroleum refineries and petrochemical plants have organized a preventive program, which according to the American Petroleum Institute [*1*], is referred to as a "reliability program."

Reliability programs

A good reliability program includes various detailed inspection programs performed both during heater operation and overhaul or occasional maintenance shutdown periods. Continuous assessments of the remaining lifetime of tubes and the supervision of heater performance are also included in the program of many petroleum refineries. Although reliability programs have proven successful during long periods of heater operation, many heaters are still victims of tube-deterioration mechanisms. That is because heater operators or field engineers are often kept out of the loop of a reliability program.

It is true that deterioration mechanisms are mostly categorized as complex metallurgical phenomena, and inspection engineers with degrees or specialties in metallurgical engineering should evaluate and explicate them; but after the inspection or evaluation stage, the main root causes of such problems are mostly simple and can be explained to an operator with the aid of fact sheets or flowcharts. If the operators are being kept out of the loop, it is always possible for personnel to misinterpret a sign of tube deterioration. And since heater inspectors are not around all of the time, such misinterpretations could easily lead to a disastrous event.

FIGURE 1. Misunderstanding warning signs led to a dramatic internal coke build up, followed by high tube metal temperatures, creep and finally tube rupture in one of the pass outlets of a visbreaker plant heater. Operators had unintentionally ignored high tube-skin temperatures for one week

Dangers of misunderstandings

As an example, consider Figure 1, which demonstrates a dramatic tube rupture case that was the result of misunderstanding the warning signs and a lack of root-causes knowledge on the part of operating personnel. In this particular case, the pass outlet was near the internal header-box refractory linings. Because of this, the operators had unintentionally ignored high tube-skin temperatures and assumed that they were misreading the refractory wall temperature by the infrared pyrometer. If they were aware of other warning signs and root causes of internal coke buildup (fouling), such as back pressure in the specified pass, maybe serious courses of action would have been considered before raising the tube metal temperature to values that eventually caused severe creep and tube rupture.

FIGURE 2. In this example of good troubleshooting, operators observed a failed tube hanger, which triggered the alarm for possible roof tubes sagging and led to the heater shut down for maintenance and hanger repair

Explaining the root causes of the deterioration mechanisms to the operating team can prevent deterioration in the first place. It is important that the inspection team arrange meetings in which operating personnel walk through the chain of events and performance imbalances that lead to a tube failure.

As another example, the situation shown in Figure 2 was dealt with before the shield section tubes experienced serious sagging, which could easily lead to tube rupture and possible explosion. As the operators were aware of the possible threat of roof tubes sagging (in case of fallen or failed tube hangers), observing the failed hanger at the floor of the heater

TABLE 1. TYPICAL FIRED HEATER TUBE -DETERIORATION MECHANISMS AND ROOT CAUSES

Problem category	Problem sub category	Flame impingement	Heat flux imbalances	Improper fuel pressure	Heavy fuel-oil combustion problems	High content of impurities in fuel	Low process fluid flowrate	Upstream equipment malfunction	Heavy hydrocarbon molecules pyrolysis (coke buildup)	Mineral sediments	Thermal shock	High firing rate	Chemical composition of process fluid (critical species)	Improper two-phase-flow regime*	Air Leakage	Poor heater-casing design	Misplaced or failed tube support or hanger	High pressure drop across heater passes	Control systems malfunction	Increased heater charge rate	Cyclic heat-load variations	Faulty roll procedures or workmanship	Undue force to close fittings	Improper mechanical or steam air decoking procedures	Refractory damages or improper refractory repair
Root Cause																									
Hotspot	---	•	•	•	•		•		•	•		•													
Fouling	Internal fouling	•	•	•	•		•	•	•	•		•													
	External fouling	•	•		•	•					•	•													•
Corrosion	Internal corrosion	•						•	•	•			•	•											
	External dew-point corrosion				•	•									•	•									
Creep	Minor creep	•	•	•			•				•	•													
	Bulging	•	•	•					•	•															
	Bowing and sagging	•	•	•	•		•		•	•		•					•								•
Vibration	---								•	•				•			•	•	•						
Erosion	---	•	•																	•					
Thermal fatigue	---										•	•									•				
Mechanical deterioration	---																•					•	•	•	•

Note: * In this article, the term "improper two-phase-flow regime" refers to "slug flow" regime only and complex two-phase-flow phenomena caused by poor design, or improper operating conditions (problems like sudden flash evaporation or mist flow) are beyond the scope of the current study.

triggered an alarm, which led to the shutdown of the heater for maintenance and hanger repair.

A good troubleshooting guide can demonstrate the fact that failed roof hangers are caused by overheating in the convection section. In this vein, by monitoring burner flame heights and burner fuel pressures (controlling the amount of heat released), as well as monitoring bridge wall temperature, operators can prevent this phenomenon in the first place.

Troubleshooting

Even if a company offers proper training courses for personnel, and has an effective reliability program and an effective schedule of visual inspections, these measures will not reduce the importance of practical troubleshooting knowledge. An operator without proper knowledge and understanding of root causes and a troubleshooting sequence would ignore or misunderstand vital signs of a possible tube-deterioration mechanism.

In this article we propose a simple root-cause analysis and also a computerized troubleshooting algorithm that directs the heater operator from one root cause of a possible tube-deterioration mechanism to another, in sequence. The algorithms indicate how each of the improper performances for a given cause is to be corrected, and continues until all possible causes for tube-deterioration mechanism can be corrected.

Tube-deterioration mechanisms

According to the valuable references listed at the end of this article [*1, 3–4*], as well as our field experience, typical fired-heater tube-deterioration mechanisms that may lead to tube failure can be classified into the following 12 main categories:

1. Local or longitudinal hotspots
2. Internal fouling
3. External fouling
4. Internal corrosion
5. Creep (general or minor creep)
6. Bulging
7. Bowing and sagging
8. Vibration
9. External dew point corrosion
10. Erosion
11. Thermal fatigue
12. Mechanical deterioration

Root-cause analysis

It should be noted that before entering the root-cause-analysis phase, one should not neglect the possibility that the material of construction used for the heater tube can be a possible cause of some of the problems referred to above. Thus, readily available data for allowable stress and corrosion rates for various tube alloys, as a function of temperature, should be made available from appropriate tube manufacturers. These data should

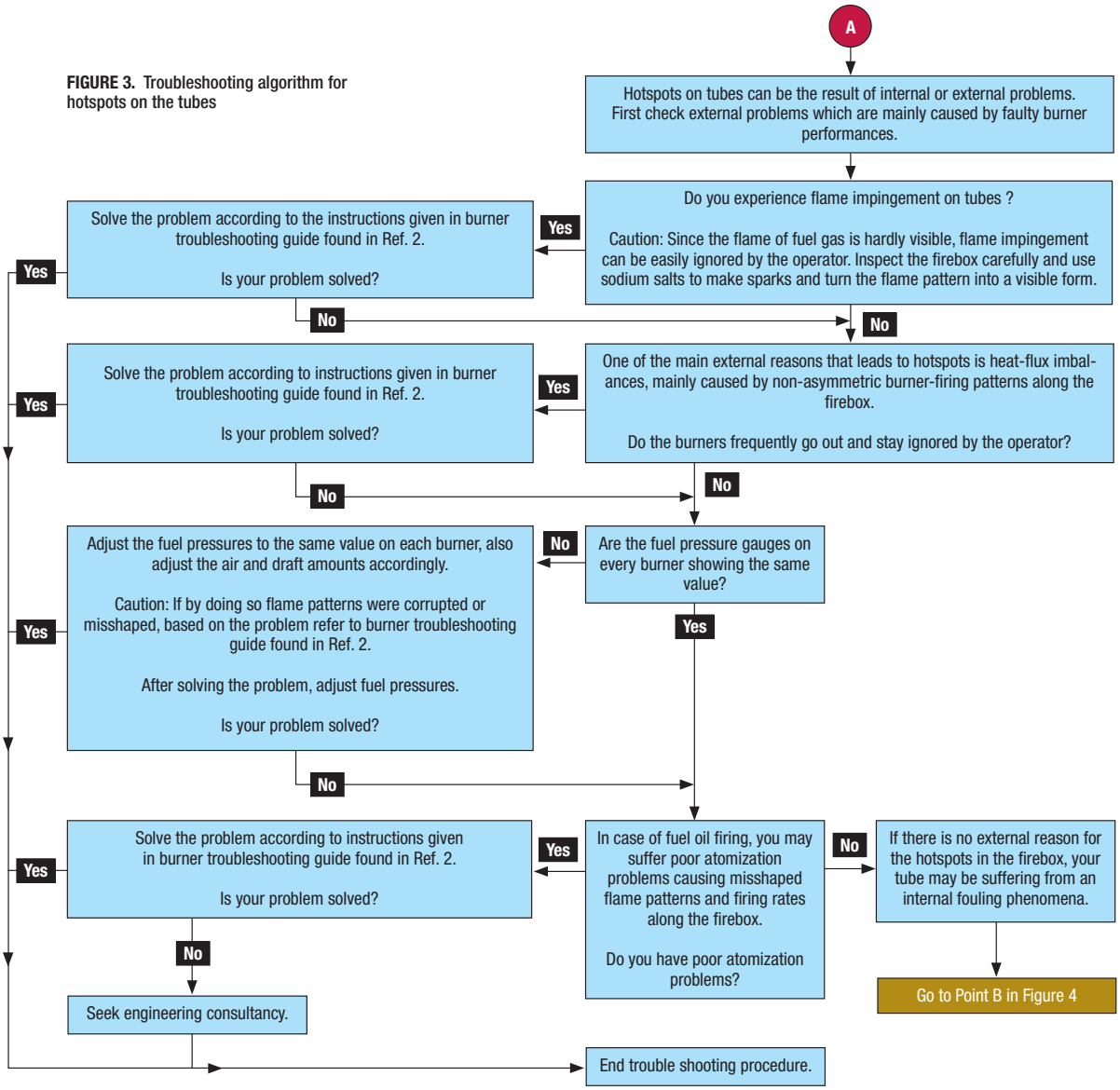

FIGURE 3. Troubleshooting algorithm for hotspots on the tubes

be checked before taking any step for understanding the root causes of tube-deterioration mechanisms.

In order to analyze each deterioration-mechanism category and its subcategories in the most concise and efficient way, a root-cause-analysis table is proposed (see Table 1).

By understanding the root causes of tube-deterioration mechanisms, one has passed through the primary step of tube-damage troubleshooting. Now what matters most is the proper sequence of troubleshooting actions, which are provided by comprehensive algorithms described in the next section.

Troubleshooting algorithms

The comprehensive troubleshooting algorithm is based on the logic depicted in Figures 3 to 6 (and continues in Figures 8–15 at www.chemengonline.com), and has been successfully used to recognize what the tube-deterioration mechanism might be, indicate the cause of the problem and correct the heater defect, so as to achieve the proper tube operating lifetime.

A practical example

Let's assume that an operating team tries to prevent a future tube failure like the one shown in Figure 1. In order to achieve this goal, it is obvious that they need to troubleshoot the deterioration mechanisms that are responsible for this event. First of all, an inspection team should identify the nature of tube-deterioration mechanisms that have led to such a disaster. A preliminary analysis would demonstrate that severe tube creep accompanied by internal fouling (coke buildup) are to

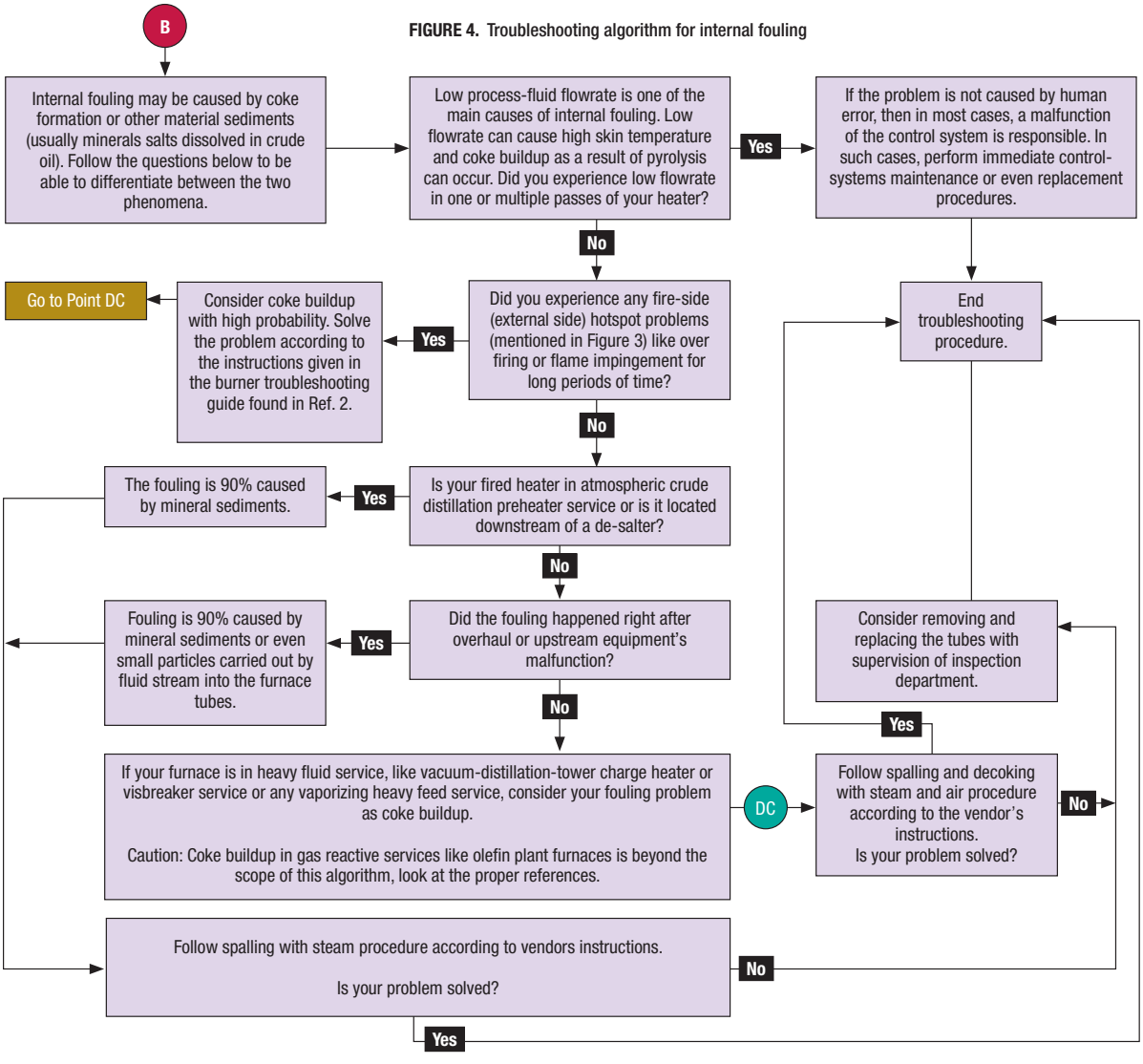

FIGURE 4. Troubleshooting algorithm for internal fouling

be blamed. This particular heater is in visbreaker service, which can be classified as a thermal cracking process. In thermal cracking of heavy petroleum cuts, coke formation is an unwanted side reaction that cannot be eliminated, but the reaction rate and duration can be controlled and reduced by maintaining proper operating conditions. In some cases the interval between decoking processes can be extended by up to three to four years.

In this particular case, unwanted coke deposition had occurred during the first year of an operating period. This event was unpredicted and surprising for the operators. Internal fouling, caused by rapid local coke formation, made an insulating layer, which in turn led to higher tube skin temperatures for long periods of time. In this vein, high tube-skin temperature led to severe creep and eventually disastrous tube rupture. In order to solve this problem and prevent it from ever happening again, the main cause — internal fouling — should be clearly understood and analyzed. By taking a look at Table 1, one can find the root causes of internal fouling, which are as follows (not necessarily in order of priority):

1. Flame impingement
2. Heat flux imbalances
3. Improper fuel pressure
4. Heavy fuel-oil combustion problems
5. Low process fluid flowrate
6. Upstream malfunction of equipment
7. Pyrolysis of heavy hydrocarbon molecules (coke buildup)
8. Mineral sediments
9. High firing rate

With the exception (in some cases) of root-cause Number 9 (high firing rate) [*2*], all the other causes can be treated by the stepwise troubleshooting procedure outlined in this article.

In order to solve the internal fouling problem, the operator can start with the procedure given in Figure 4. This procedure starts with the

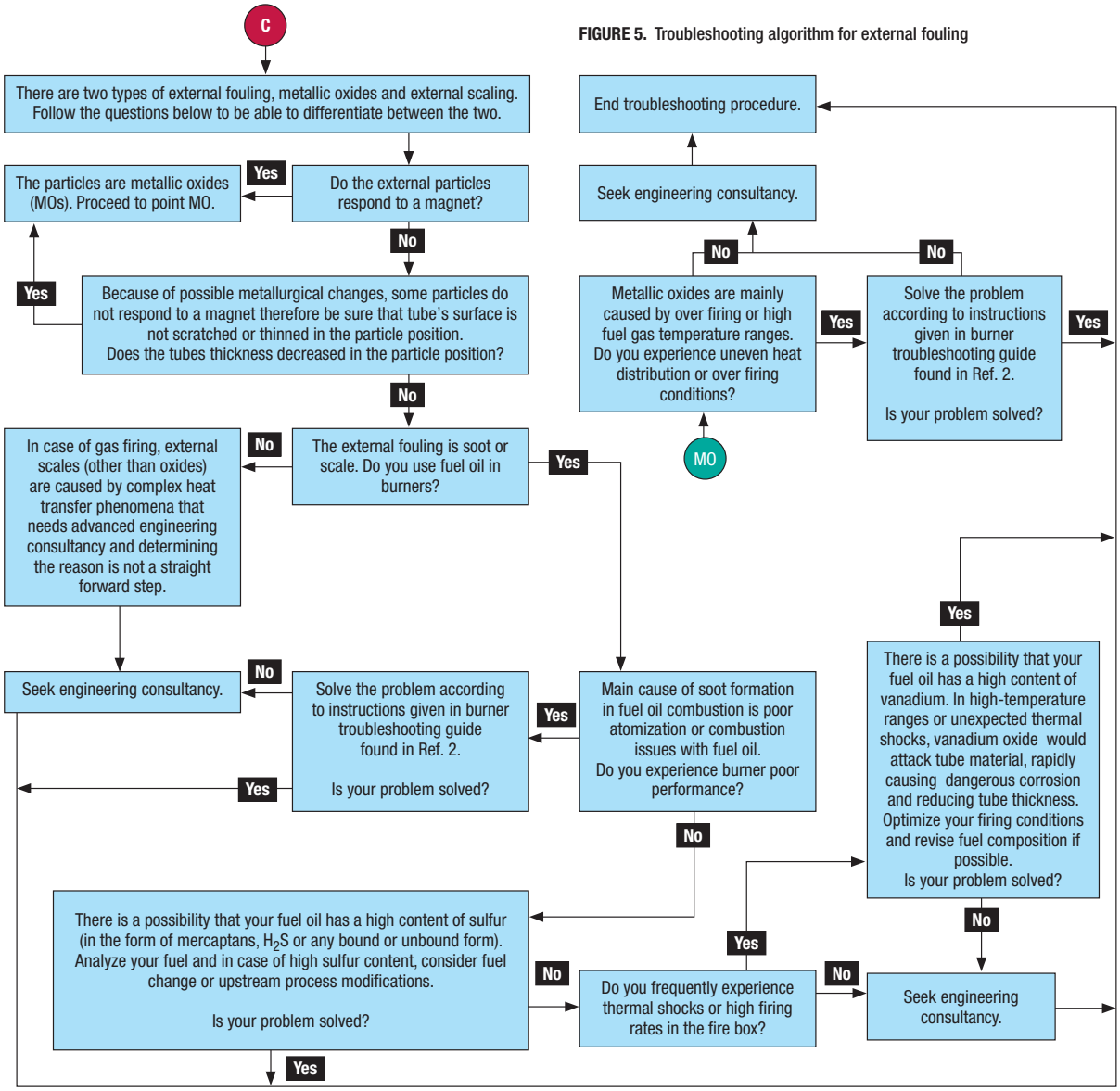

FIGURE 5. Troubleshooting algorithm for external fouling

simplest solution, which is solving low process-fluid flowrate in heater passes. Low process-fluid flowrate can cause high tube-skin temperatures that can lead to internal fouling. It should be noted that human error and control-equipment malfunction are the main causes of low process-fluid flowrate. It is mandatory to prepare a regular program for checking control equipment accuracy. Also, assign *experienced* personnel to control sensitive equipment, such as fired heaters.

If the problem is not related to this cause, the operator is asked to check for burner firing problems, like flame impingement, heat-flux imbalances, improper fuel-oil pressure or heavy fuel-oil combustion problems. If any of these problems have been observed for long operating periods, one can almost be certain that the internal fouling is due to coke buildup. In order to solve any burner-firing problem, the operator can refer to the detailed troubleshooting algorithms described in Ref. 2.

Mineral sediments fouling, which is not the case in this example, may happen in crude charge heaters that are placed after de-salters and heat exchanger networks in most refineries. Apparently, if the heater is in crude charge service, checking the de-salter's malfunction should be the next step in the troubleshooting algorithm. If this is not the case, upstream equipment malfunction can be the next cause. Small particles carried by a fluid stream can plug heater tubes and reduce flowrate locally or in a whole pass. Similar to low process-fluid

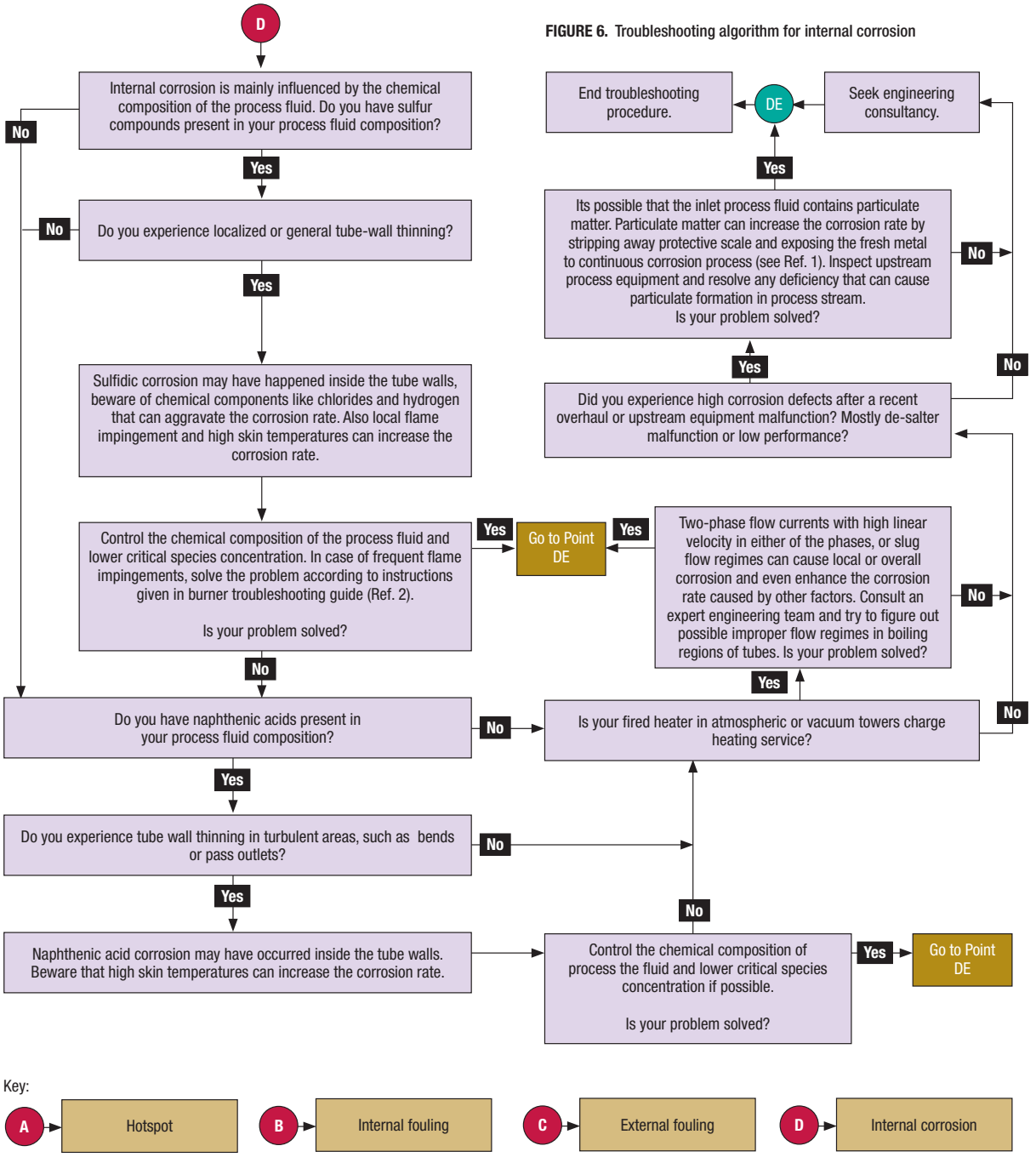

FIGURE 6. Troubleshooting algorithm for internal corrosion

flowrate, this can lead to severe internal fouling. Operators should be warned about the possibility of this problem, specifically after overhaul or upstream equipment malfunction and maintenance.

As the next step, the nature of the process should be noted. For visbreakers or any service in which heavy feed is vaporizing, coke buildup is a likely possibility. As coke formation in these kinds of heaters is highly anticipated, controlling operating conditions, especially the items mentioned in previous steps of this algorithm, is very important and vital. By following the right steps, operators may control — and even in some cases eliminate — coke buildup phenomena.

Other steps of this algorithm are dedicated to the decoking and spalling practices that should be followed, depending on the nature of the internal fouling problem.

Following this procedure would usually eliminate and even prevent

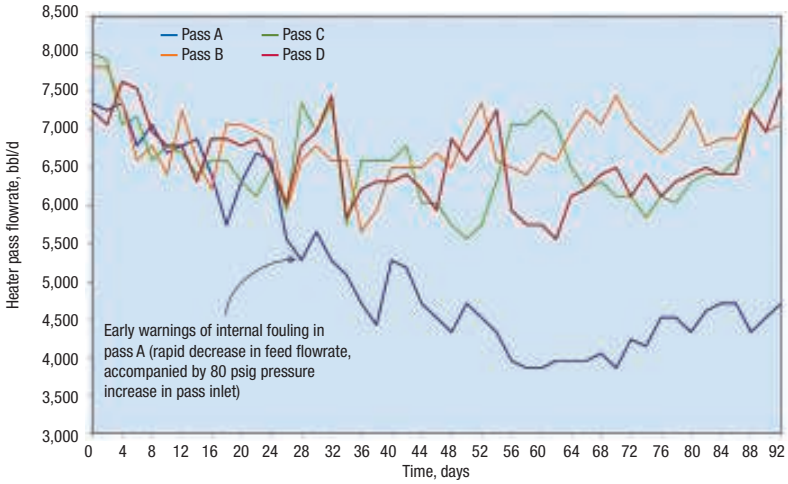

FIGURE 7. This graph shows the operating history of the process fluid flowrate in four passes of a vacuum distillation unit charge heater. Ignoring early signs of internal fouling caused by rapid coke buildup, led to disastrous tube rupture, like the one depicted in Figure 1

future internal-fouling problems, as for the case history shown in Figure 1. Surveying the operating history of the heater proved that long-time local flame impingement was the main cause of this event, and tuning the draft and excess-air amounts could have solved the problem in the first place.

As a final note, we should add that our experiences have proven that in similar case histories, increasing the awareness and knowledge of operating teams about the initial signs of internal fouling phenomena is as important as knowing the troubleshooting sequences. For example, in a similar case that happened in a vacuum charge heater, operators were too much dependent on infra-red pyrometer measurements of tube-skin temperatures. That misreading of the skin temperature made them ignorant to the actual problem that was taking place. As depicted in Figure 7, the process fluid flowrate had decreased during coke buildup and simultaneously, the heater pass inlet pressure increased 80 psig. These two events are very obvious early warnings of internal fouling in the specified heater pass (Pass A of Figure 7).

The operators had simply related the decreased flowrate to the control equipment malfunction and ignored it. If the operators were aware of other warning signs of possible internal fouling, this problem may not have endured for such a long operating period that would lead to tube rupture. This is another reason for the necessity of an operator-involved reliability program in refineries in addition to good troubleshooting knowledge and training.

Computerized algorithm

A computer program (computer wizard) can easily be developed based on logic described in Figures 3–6, and 8–15. By using this program in industrial environments, like petroleum refineries and petrochemical plants, operators will be able to understand and correct the root causes of a possible deterioration mechanism in more efficient ways. As a result fewer maintenance operations or mandatory tube replacements will be needed.

It should not be forgotten that the main cost saving and also safety benefits of this program will result from the following:

- Fewer forced direct-fired-heater outage events due to tube failure
- Elimination of disastrous events, such as a heater explosion caused by unpredicted tube ruptures
- Extending the operating lifetime of heater tubes
- The possibility of increasing throughput and decreased downtime for decoking operations ■

Edited by Gerald Ondrey

Acknowledgment

The authors wish to thank the help and contribution of Alan Cross. He is always a mentor to us who gives us the courage and motivation for preparing and submitting our experiences in engineering papers.

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The complete set of troubleshooting algorithms is available online at www.chemengonline.com

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Optimizing Pressure Relief Systems

Alternative designs for pressure relief systems may offer investment cost savings

Peter Cain
Process Consultant

IN BRIEF

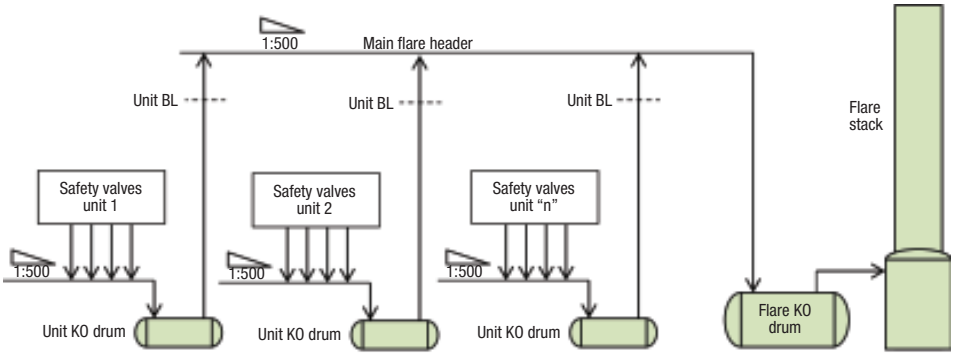

FIGURE 1. This sketch shows a simplified pressure-relief system for a petroleum refinery

Pressure relief systems for the chemical process industries (CPI) are essential to prevent a process system, or any of its components, from being subjected to pressures that exceed the maximum allowable accumulated pressure, by emergency venting to a closed relief system.

These relief systems are normally very conservatively designed. For large, new petroleum refineries with capacities around 300,000 barrels/day (bbl/d), this can result in costs of up to 1% of the total refinery capital investments (Capex).

This article presents simple project alternatives to traditional closed relief systems [*1*], based on American Petroleum Institute (API) standards, that can present significant investment-cost reductions.

Background

Overpressurization of process units can occur due to several reasons as indicated in API-521 [*2*]. Some of those reasons are the following:

- General power failure
- Cooling water failure
- Instrument failure
- External fire

Normally, general power failure or utility failure results in the highest vapor load for a closed pressure-relief system, and is therefore used as the design case. Before sizing a closed relief system, it is advisable to reduce these very high vapor loads by the following:

1. Use high-integrity protection systems (HIPS) as recommended in API-521, which can result in a significant reduction of the vapor flowrates to the flare.
2. Realize dynamic-system load modeling. This analysis for a complete petroleum refinery is very complex and is not normally used, but it can also result in flowrate reductions.

After defining the minimum possible vapor flowrates that correspond to the overpressure relieving rates defined by the design case, the closed relief system may be sized.

Traditional closed systems

A closed pressure-relief system is designed to safely control overpressurization of process units during emergencies by relieving the vapors to the flare, which destroys hydrocarbons in a high-temperature flame. Figure 1 shows a typical closed relief system that collects vapors and liquids in process-unit headers and separates the liquid in process-unit knockout (KO) drums before sending the vapor phase to the main flare header, and finally to the flare unit for destruction.

In the traditional system, the unit KO drums and the flare KO drums are projected for the maximum vapor and liquid flowrates as determined from the analysis of the overpressure causes and indicated in API-521 [*2*].

The KO drums, process units and flare unit, are sized to separate particles in the range of 300–600 μm in diameter, and to hold liquid discharge for 20 to 30 minutes as per API-521 item 7.3.2.1.2 for these maximum flow conditions.

The unit flare headers and the main flare header are also sized for these maximum flowrates. All the headers slope with a minimum inclination of 1:500 toward their respective KO drums, and are continuously purged

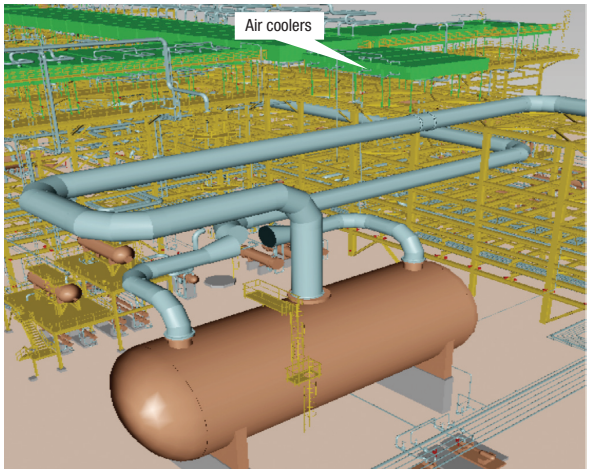

FIGURE 2. This large, horizontal process-unit KO drum requires the air coolers to be mounted very high

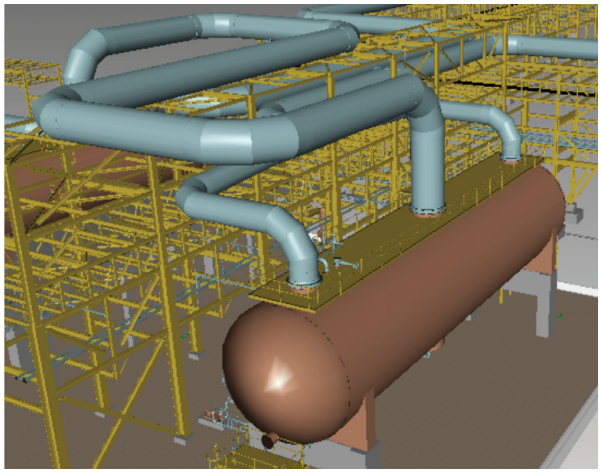

FIGURE 3. A large, horizontal flare-unit KO drum can require a very high piping arrangement

using combustion gas or nitrogen from the upstream end toward the KO drums to avoid ingress of air into the system.

Optimized closed systems

The calculation criteria for sizing the flare KO drums and process-unit KO drums result in very large vessels. This implies the need to install the collection headers very high above grade level, since they must drain to the KO drums. Equipment, such as air coolers that must be mounted above the process unit headers are consequently also very high. This requires long stretches of process piping to and from the equipment. Figure 2 shows such a situation.

If it was possible to change the design criteria for the process-unit KO drums, the process-unit flare header and the air coolers may be installed at a lower level with considerably lower installation costs as a result of the use of less structural steel and process- and flare-header piping.

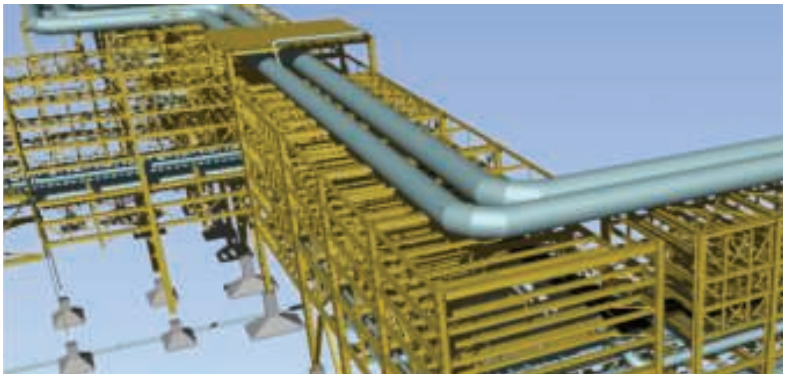

FIGURE 4. This sketch depicts a very high pipe rack to support the main flare header

At the flare unit, the KO drum is even larger than the process unit drums, and as a result, the main flare header at the inlet to the vessel is very high, as can be seen in Figure 3. Consequently, the main flare header at the flare-unit battery limits (BL) is also very high. Since the flare header in large, new, petroleum refineries is normally very long (about 2 km), it means that at the farthest point from the flare unit the header is at least 5 m higher than at the flare-unit battery limits. This installation requires a lot of structural steel to maintain the flare header at the required height, and consequently high investment costs for the pipe rack are required (Figure 4).

The criteria used to size the KO drums for carryover of droplets that are 600 µm in diameter is, according to API-521, to eliminate the possibility of incomplete combustion with excessive smoking, possible "burning rain," and even flame-out of the flare.

It is clear that the flare unit KO drum must be sized according to this limitation as it is upstream of the flare. However, this limitation is not necessary for the process unit vessels, as these are upstream of the flare-unit KO drum. In this case, if large droplets are carried over from the process-unit KO drums, the flare-unit KO drum will retain them and maintain adequate conditions for the flare.

API-521 item 6.4.3.6.7 presents a clear explanation of the design parameters for these vessels:

"*Some flare systems require a flare knockout drum to separate liquid from gas in the flare system and to hold the maximum amount of liquid that can be relieved during an emergency situation.*

"Knockout drums are typically located on the main flare line upstream of the flare stack or any liquid seal. If there are particular pieces of equipment or process units within a plant that release large amounts of liquid to the flare header, it is desirable to have knockout drums inside the battery limits to collect these liquids. This reduces the sizing requirements for the main flare knockout drum, as well as facilitates product recovery.

"In general, a flare can handle small liquid droplets. However, a knockout drum is required to separate droplets larger than 300 µm to 600 µm in diameter in order to avoid burning liquid outside the normal flame envelope. If unit knockout drums are provided upstream of the main flare knockout facilities, these drums may be sized to separate droplets typically greater than 600 µm in diameter. The use of unit knockout drums effectively reduces the sizing requirement for the main flare knockout drum and facilities, See 7.3.2.1.

"The liquid hold-up capacity of a flare knockout drum is based on consideration of the amount of liquid that can be released during an emergency situation without exceeding the maximum level for the intended degree of liquid disengagement. This hold-up should also consider any liquid that can have previously accumulated within the drum that was not pumped out. The hold-up times vary between users, but the basic requirement is to provide sufficient volume for a 20 min to 30 min emergency release. Longer hold-up times might be required if it takes longer to stop the flow. It is important to realize as part of the sizing considerations that the maximum vapor release case might not necessarily coincide with the maximum liquid. Therefore, the knockout drum size should be determined through consideration of both the maximum vapor release case as well as the release case with the maximum amount of liquid."[2]

Analyzing the above, we can conclude the following:

1. Process unit KO drums are not mandatory.
2. There is no size limit for droplet carryover of process-unit KO drums — larger than 600 µm in diameter is permitted.
3. Process-unit KO drums, if installed, are provided to collect liquid.
4. Flare-unit KO drums must be sized in order to retain droplets larger than 600 µm, as it is upstream of the flare.
5. Process-unit KO drums should be designed to provide sufficient volume for 20–30 min emergency liquid release unless the expected response time is longer.

Taking into consideration the above conclusions, the process-unit KO drums can be sized considering basically only the liquid hold-up time. The flare-unit KO drums, located downstream, will collect liquid droplets larger than 600 µm in diameter. Therefore, the criteria for sizing process-unit KO drums can be changed from separation of droplets greater than 600 µm in diameter to liquid hold-up.

As there is no worry about droplet carryover, it is possible to consider the use of vertical KO drums in the process units instead of a horizontal vessel, as they present several advantages when designed only for the collection of liquid as seen below:

- Smaller vessel
- Has a smaller footprint and can be installed closer to the pipe rack
- The height of the process unit header is lower, which saves on structural steel in the pipe rack
- The arrangement of the process unit header can be simplified, resulting in a smaller total length
- Air coolers, if installed, can be lowered, reducing process piping to and from the equipment
- Reduced weight of the pipe rack and KO drum reduces foundation requirements

These vertical KO drums can be designed without internals, and with the outlet flare nozzle at 180 deg from the inlet nozzle and at the same elevation, as the liquid droplet

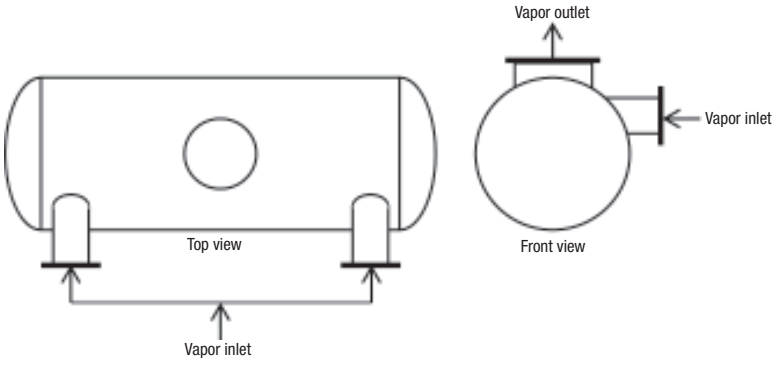

FIGURE 5. This flare-unit KO drum is equipped with horizontal inlet connections

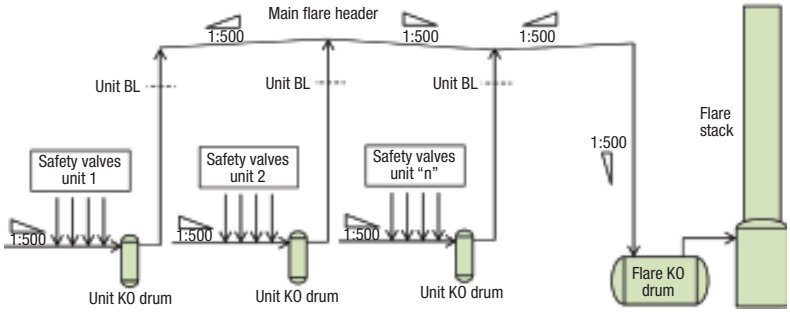

FIGURE 6. This schematic shows a closed pressure-relief system using the alternative suggested here

carryover is not in question. However, the designer should avoid very large droplet carryover, which results in vessels with a smaller length-to-diameter ratio than usual for vertical gas-liquid separation vessels. The reason to remove very large droplets in the process units is not to overload, with liquid, the new main header proposal presented below.

As can been seen in API-521 item 6.4.3.6.7 (quoted earlier), process-unit KO drums are not mandatory. But, because condensation always occurs in flare headers, it is recommended to maintain the process-unit KO drum unless this header can be drained to the main flare header outside the battery limit (OSBL).

This change of design criteria for the process-unit KO drums will reduce the vessel volume by up to 80%, resulting in a considerable investment-cost reduction for the inside the battery limit (ISBL) relief system.

OSBL cost reductions may be obtained for the main flare header by reducing the elevation above grade level of this very large (diameters around 80 in.) and long pipe. This

can be done in two steps — the first of which is to reduce the header height at the flare unit battery limits. This may be done by a simple alteration of the header's inlet piping arrangement to the very large, horizontal flare-unit KO drum — which can be over 8-m dia. — by changing the vertical inlet connections to horizontal ones, as indicated in Figure 5. In large petroleum refineries, this alteration to the inlet connections can result in a reduction of the header height at the flare unit battery limits by more than 4 m.

The second step is to reduce the large increase in height of the main flare header from the flare unit to the farthest process unit because of the required slope of 1:500. This may be achieved by installing a vessel and pumps along the pathway to collect condensate, thus dividing the header into two approximately equal parts. The first part is from the farthest process-unit drains to the header collection vessel, and the second is from this vessel to the flare-unit KO drum (an intermediate main-header KO drum).

This suggestion is based on API-521 item 7.3.1.3.8, which states: "A small drain pot or drip leg can be necessary at low points in lines that cannot be sloped continuously to the knockout or blowdown drum." [2]

An alternative to the installation of a second main-header KO drum and pumps, which require additional investment costs, is to integrate the process units with the main flare header by carefully designing the process-unit KO drums and headers.

This alternative is to use some, two or three, of the process-unit KO drums to receive condensate from the OSBL main-flare header. In this case, it is important to make sure that the liquid hold-up capability of the selected process-unit KO drums considers this additional service requirement and that they are adequately sized. It is also necessary to make sure that the response time used to size all the process-unit KO drums is adequate and that large quantities of liquid will not be carried over to the main flare header. Provisions must be made to permit isolation of the process-unit KO drums used for this service from the process units during shutdown.

This installation collects condensate formed in the main flare header along its extension, reducing the amount carried over to the flare-unit KO drum and permitting a reduction in its size.

Figure 6 shows a schematic design of a closed pressure-relief system using the alternatives suggested in this section.

Further integration of the ISBL and OSBL flare projects can bring gains by considering the pressure profile of the main flare header determined by the refinery-flare design case. The pressure at the battery limit of the process unit farthest from the flare unit will be higher than the process unit closest to the flare unit. In the traditional approach, the maximum pressure at the battery limits of all the process units is defined as a constant value and is the same for all process units.

Taking this into consideration, this profile permits that the process units nearest to the flare unit can reduce the diameter of the ISBL flare headers until the maximum permitted back pressure is reached for the most critical pressure-safety valve (PSV). Normally the most critical PSV is the valve with the lowest set pressure. All ISBL headers should be designed for the maximum possible velocity and values of over 35% of the Mach number should be pursued, but limited to 50%, and approximately maintained along the ISBL header, by adjusting the diameter to minimize header costs.

The main flare header should also be sized carefully, to minimize the diameter, by considering the maximum possible process-units battery-limit pressures defined by the back pressure of the PSVs. Once more, the diameter of the header should be adjusted to maintain the vapor velocity for the design case, which is approximately constant from the farthest process unit to the flare unit.

Cost savings

As can be seen from the above discussion focused on petroleum refineries, fairly simple project considerations can reduce the cost of construction of a closed pressure-relief system. It is possible to significantly reduce the size of the process-unit KO drums, while at the same time save considerable structural steel used for the ISBL and OSBL pipe racks. It is also indicated that by careful calculations of the closed flare system with integration of the ISBL with OSBL, it is possible to reduce the flare header diameters.

In comparison with the traditional approach, this new manner to project the pressure relief system offers a reduction of about 30% in the height of the main flare header and around 20% in the height of the unit flare headers. This together with the much smaller unit KO drums, reduced header diameters and less process piping for the lowered air coolers, permits an investment cost reduction for the relief system of up to 20% as compared with the traditional project. ■

Edited by Dorothy Lozowski

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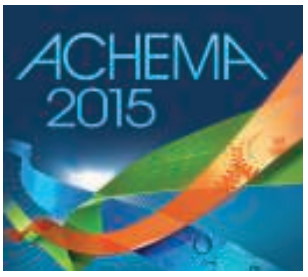
2. Pressure-Relieving and Depressuring Systems, API Standard 521, Fifth Edition, January 2007 and Addendum, May 2008.

Author

Peter Cain is a process consultant for Petrobras in Brazil (Phone: 55-21-98211-0627; Email: petercain@rocketmail.com). He has more than 40 years of experience in positions including process engineer, job leader, technical coordinator, technical manager, principal partner and consultant in the petrochemical, petroleum, chemical, industrial waste and nuclear fields. For the past 16 years, he has worked with Petrobras on the installation of several industrial units in areas such as hydrogen generation, hydrocracker and hydrotreatment units, power generation, cooling-water towers, crude and vacuum distillation and others that are parts of modern petroleum refineries. He is also participating in the basic engineering and FEED projects of two, new 300,000-bbl/d refineries and has presented several project revisions to reduce Capex and Opex. He has also realized the "clean up" of several areas contaminated with oil as principal partner and founder of a waste treatment company. Cain holds an honors degree in applied physics from Bath University in England.



Achema 2015 — the 31st world forum for the chemical process industries (CPI) — will be held June 15–19 in Frankfurt am Main, Germany. Organized by Dechema e.V. (Frankfurt; www.dechema.de), this year's event features 11 exhibition halls, which will provide a platform for over 3,600 registered exhibitors to showcase innovative products and services. Concurrently with the exhibition, an extensive technical conference will take place, with numerous panel discussions, lectures and special sessions planned. For further details on the event's agenda, please visit www.achema.de. Special focus will be given to the following topics: advances in bio-based processes; innovative process analytical technologies; and industrial water management.

Chemical Engineering, in collaboration with Vogel Media (Würzburg, Germany), will be covering Achema 2015 in the *Achema Daily*, a bilingual, daily newspaper that is distributed to event attendees. For readers unable to attend Achema 2015, a digital version of the *Daily* will also be available online.

The following show preview includes a small selection of the products and services that will be on display at the exhibition.

Burocco Industrial Valves

Use these control valves in cryogenic plants

Series 4000 control valves (photo) are designed for super-vacuum-insulated cryogenic plants, and can also be used in pilot or experimental plants. These valves are machined from stainless steel, and are rated for temperatures from –196 to 100°C. Internal parts can be removed or replaced without the need to remove the valve body from the pipeline, simplifying maintenance operations. Handwheel functionality is included for emergency operation. Hall 9.1, Stand E7 — *Burocco Industrial Valves s.r.l., Pray, Italy*
www.burocco.it

PCM Europe

Compact progressive-cavity pumps use less power

The EcoMoineau C is a stainless-steel progressive-cavity pump (PCP) that is said to be the shortest PCP on the market — 42% shorter and 57% lighter than previous PCP models. A version specific for food applications can be used in meat, animal-feed, sugar and beverage processes. The industry-specific model (photo) is suitable for use in many CPI sectors, including chemicals, minerals, paper and wastewater. The pump's patented connecting system has only three screws, and the shaft line can be removed without disconnecting from the pipes. EcoMoineau pumps are also said to use 10% less energy than previous-generation PCPs due to their lightweight construction. Hall 8.0, Stand D5 — *PCM Europe S.A.S., Levallois Perret, France*
www.pcm.eu

Anguil Environmental Systems

Energy-efficient solutions for VOC, NOx destruction

This company's vapor and oxidation systems are suitable in many abatement applications, including the destruction of volatile organic compounds (VOCs), hazardous air pollutants, oxides of nitrogen (NOx) and odorous emissions, in a wide range of processes, such as tank venting, separations, mixing, coating and more. Regenerative thermal oxidizers (photo) have an especially high destruction capability, while still remaining energy-efficient, says the company. Hall 9.1, Stand B48 — *Anguil Environmental Systems, Milwaukee, Wis.*
www.anguil.com

R. Stahl Schaltgeräte

Lightweight, long-lasting LED-based luminaires

The Exlux 6402 Series (photo) of LED-based linear luminaires is intended for hazardous-area use. These luminaires boast a lifespan of up to 100,000 operating hours and weigh around a third less than comparable products. A variety of accessories and mounting parts are available, including options for pole-mounting. Exlux devices can operate at ambient temperatures of –30 to 55°C. Two standard models are available with or without diffusers, in lengths of 700 and 1,310 mm. Hall 11.1, Stand C4 — *R. Stahl Schaltgeräte GmbH, Waldenburg, Germany*
www.stahl.de

This system performs non-destructive sealing analysis

The Induction Integrity Verification System (I^2VS; photo) provides analysis of induction-sealing integrity for bottles without causing packaging-line slowdown. Inspection is performed through the closed cap, without physical contact, in an entirely passive, non-destructive fashion. The system's infrared technology eliminates the need for conventional inspection techniques that rely on destructive and line-slowing sampling methods. When a problem is detected, the operator is notified immediately of the possible source of the defect. Hall 3.0, Stand J49 — *DIR Technologies, Haifa, Israel*
www.dir-technologies.com

Use three different media in one cycle with this cleaning machine

The RAN 3080 (photo) is an exterior washing machine that removes product residue and other contamination from glass containers using a high-pressure cleaning process. The machine consists of a rotary platform for cleaning and an identical rotary platform for drying. Pressurized air flows continuously over the containers' closure caps, preventing moisture from entering the containers. The RAN 3080 features three individual washing stations, and up to three different media can be used per cycle. Due to the strict separation of the cleaning and drying areas, the machine prevents re-contamination of the containers after washing. Depending on production requirements, the machine can be equipped with different containment devices. Hall 3.1, Stand C71 — *Robert Bosch GmbH, Stuttgart, Germany*
www.boschpackaging.com

Modular microfiltration plants for bioprocessing applications

This company's modular microfiltration plants (photo) apply a low-pressure crossflow membrane process for separating colloidal and suspended particles in the size range of 0.5–10 µm. Microfiltration is used in many applications, including fermentation, broth clarification and biomass clarification and recovery. A recent application of the modular microfiltration plant is an installation at a pilot facility where new products for third-generation bioprocesses will be studied. Hall 4.0, Stand F46 — *GEA Wiegand GmbH, Ettlingen, Germany*
www.gea-wiegand.com

This microvalve operates extremely quietly

The Type 6712 Whisper Valve (photo) is a microvalve with a height of 26 mm and a width of 7 mm, making it small enough to fit inside a miniature apparatus. The low overall weight of the Type 6712 is an advantage in dispensing, pipetting and dosing applications. With its non-impact actuator, the Type 6712 can control flowrate very quietly. The new actuator is designed to operate at a sound level below 36 dB, and the typical metal-to-metal contact noise of a solenoid valve is eliminated. Compared to similar-sized valves, the working pressure range of Type 6712 valves is very high, at 3 bars during switching and 8 bars during the flushing process of the open valve. Hall 11.1, Stand E62 — *Bürkert Fluid Control Systems, Ingelfingen, Germany*
www.burkert.de

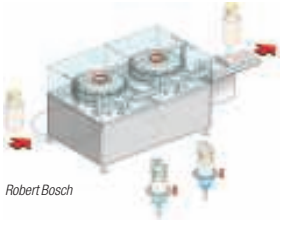
Polypropylene structured packing reduces clogging risks

This company's 2H Massdek structured packing (photo) is intended as an alternative to random packing in packed columns and gas scrubbers. Made of polypropylene, these packings operate with very low pressure drops, and maintain the original gas and liquid distribution, even with large bed heights. When compared to random packings, these structured packings have less horizontal surfaces, and are characterized by uniform distribution of specific surface area throughout the column's cross section, minimizing the risk of clogging. Plastic construction gives 2H Massdek packings long-term stability and allows them to be recycled rather than disposed. Hall 4.0, Stand F46 — *GEA Heat Exchangers, Bochum, Germany*
www.gea-heatexchangers.com

This valve series has extensive optimization potential

This company's 290 Series includes a wide range of valves for many fluid applications and media types. Stainless-

DIR Technologies



Robert Bosch

GEA Wiegand

Bürkert Fluid Control Systems

GEA Heat Exchangers

ASCO Numatics

steel and bronze bodies are among the available options, and many accessories can be added to further optimize the product. The motorized version (photo) is designed for applications where electrical actuation is required. This lightweight valve has a low power consumption of just 12 W and proven operation for more than 1 million cycles, according to the company. Also included in the 290 Series are proportional valves. *Hall 9.0, Stand B4 — ASCO Numatics, Lucé, France*
www.asconumatics.eu

Linear actuators that monitor crucial functions

The PSF (photo) and PSF-M (with manual override) models of linear actuators are designed for industrial applications, as well as for the heating, ventilation and air-conditioning (HVAC) sectors. In the PSF Series, an integrated power spring activates a fail-safe functionality in the case of power loss. The PSF-M model is operated by using a handwheel or two local-control buttons. Important actuator functions, such as thrust, supply voltage, set value and temperature are monitored. Additional accessories, including two-signal relays and heating implements are available. Hall 8.0, Stand J36a — *PS Automation GmbH, Bad Dürkheim, Germany*
www.ps-automation.com

PS Automation

These positioners include integrated stroke-testing

The Trovis Safe Series of positioners has been optimized for use with on/off valves in safety-instrumented systems, and is certified to comply with Safety Integrity Level (SIL) requirements. Partial-stroke testing capabilities are integrated into the positioners, which allow for early fault detection in pneumatic shutoff valves. Partial-stroke testing can be started either manually or automatically. Test data are saved in the positioner, and the condensed state indicates the valve status. Other features of Trovis Safe positioners include discrete signal analysis and ready-configured parameters for shutoff valves. Hall 11.1, Stand C75 — *Samson AG, Frankfurt am Main, Germany*
www.samson.de

Ekato RMT

SensoTech

Abrasion-resistant ceramic mixer components

This company's line of ceramic-containing impellers and other mixing components (photo) boasts a significant improvement in lifetime due to the inherent resistance of ceramic materials to wear, abrasion and corrosion. Should a replacement component be required, only the actual worn-out part needs to be replaced, and the other parts, such as hubs and blade holders, can remain within the vessel. Specific areas of application for ceramic mixing components include pigment production and mining processes with concentrated suspensions, as well as any process that demands high product purity with respect to traces of metal abrasion. Hall 5.0, Stand D42 — *Ekato RMT GmbH, Schopfheim, Germany*
www.ekato.com

A test system for determining water-vapor transmission rate

The W3/330 is a test system for determining water-vapor transmission rate that is suitable for use with flexible films, sheets, foils and packaging materials. The system's patented design allows for the simultaneous testing of up to three specimens with independent results. The water-vapor transmission rate is obtained by analyzing and calculating the electrical signals that are generated as the water vapor permeating from the specimen is carried via dry nitrogen over an electrolytic sensor. The system can be easily connected to a maximum of 10 instruments to accomplish up to 30 tests at the same time. Hall 4.2, Stand N36 — *Labthink Instruments Co., Jinan, China*
www.labthink.com

Monitor complex reactions with these liquid analyzers

LiquiSonic analyzers (photo) provide monitoring of process parameters, such as concentration, and can be integrated into many processes, including gas scrubbing, phase separations, neutralizations, dissolution or blendings. The instruments can also monitor complex reactions, such as crystallization (where saturation degree, crystal content and metastable range

can be analyzed) or polymerization. Based on sonic-velocity measurement, the analyzers provide high precision and stability with minimal maintenance requirements, says the company. Hall 11.1, Stand F75 — *SensoTech GmbH, Barleben, Germany*
www.sensotech.com

A versatile pipette designed with ergonomics in mind

Bravo pipettes (photo) are ergonomically designed to provide a balanced weight distribution throughout the pipette, which ensures comfort during extended pipetting periods. Fully autoclavable, these pipettes have a volume range of 0.1 µL to 10 mL. Bravo pipettes are compatible with all major brands of tips, and a built-in oversized indicator allows for easy volume monitoring and precise adjustment. Hall 4.2, Stand B48 — *Capp ApS, Odense, Denmark*
www.capp.dk

This tablet-printing machine provides high resolution

The Agate DSL (photo) is a tablet-printing machine that prints logos and authentication labels onto a variety of solid-dosage products, including soft- and hard-gel capsules and freeze-dried tablets. The machine's indirect-transfer printing technique immobilizes the product under the printing head, allowing for very accurate linear printing, with a resolution of up to 0.1 mm. Additionally, an optional camera-inspection system with individual rejection can be integrated into the machine. Hall 3.1, Stand C98 — *Printing International N.V./S.A., Aalter, Belgium*
www.printinginternational.com

This system optimizes up to eight reactions simultaneously

With the CM Protégé reaction-optimization system (photo), researchers working in pharmaceutical and fine-chemical development can fully optimize up to eight reactions simultaneously. Each reactor can be independently heated (up to 200°C) and pressurized (up to 400 psi) while being stirred overhead. The system also provides fully automated dispensing and sampling at reaction conditions without the risk of sample loss, allowing users to profile reaction kinetics and perform design of experiments (DoE) studies earlier. Hall 4.2, Stand P63 — *Freeslate, Inc., Sunnyvale, Calif.*
www.freeslate.com

Fine particle-size separation for wet or sticky materials

The ScreenX product line consists of multi-frequency vibrating (MFV) sieves that are able to achieve particle-size separation in a size range of 10 mm down to as fine as 7 µm. With its patented MFV technology, the ScreenX line is said to be especially suitable for screening materials that are wet, sticky, prone to agglomeration or chemically aggressive. The rectangular, double-decker RS 2310 model (photo) has been used in numerous applications, including aggregates, mining and glass, with capacities as high as 15,000 kg/h. Hall 6.0, Stand E81 — *Cuccolini S.r.l., a Virto Group company, Reggio Emilia, Italy*
www.virtogroup.com

Use this TOC analyzer for ultra-pure water applications

The QuickTOCPurity (photo) is an analyzer customized to measure total organic carbon (TOC) for pure and ultra-pure water applications. The sample is introduced via an injection loop, which prevents environmental influences on the sample. Inside the oven, thermal oxidation of the sample occurs at 1,200°C, after which the produced CO_2 is measured by a non-dispersive infrared (NDIR) detector. Up to six sample streams can be measured in one unit, and integrated calibration and validation techniques enable operators to check and monitor the analyzer remotely. Hall 11.1, Stand C87 — *LAR Process Analysers AG, Berlin, Germany*
www.lar.com

A rupture disc specially designed for transport containers

The Intermodal Container Disc (ICD; photo) is a fully lined rupture disc that provides high-performance overpressure protection with an operating ratio of up to 90% combined with a ±5% burst tolerance. When directly installed between industry-standard flange fit-

Capp ApS

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LAR Process Analysers

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tings, the ICD can protect containers used for carrying gases and liquids, complying with several international standards relating to the transportation of hazardous materials. The disc can also be used in conjunction with traditional safety-relief valves. Hall 9.0, Stand B45 — *Elfab Ltd., North Shields, U.K.*
www.elfab.com

This powder rheometer can test many bulk properties

The FT4 Powder Rheometer (photo) uses a patented dynamic methodology, a fully automated shear cell and several bulk-property tests, including density, compressibility and permeability, to quantify powder properties in terms of flow and processability. The FT4 delivers data that help support longterm optimization of powder processes, and accelerates research and development efforts, says the company. Industries where the FT4 is applicable include pharmaceuticals, chemicals, toners, foods, coatings, metals, ceramics and cosmetics. Hall 4.2, Stand L36 — *Freeman Technology Ltd., Tewkesbury, U.K.*
www.freemantech.co.uk

These expansion joints require no protective sleeve

The ERV-BR is a rubber expansion joint (photo) constructed from a highly abrasion-resistant, specialized rubber compound. Except for cases of extreme strain (for instance, sharp and rough-edged matter), there is no need to use an additional inner-protective sleeve with the ERV-BR. Suitable for slurries, sludges, emulsions, and dusty or powdery products, these joints are available in sizes from 25 to 300 mm, with larger dimensions available by request. Hall 8.0, Stand L93 — *Elaflex Gummi Ehlers GmbH, Hamburg, Germany*
www.elaflex.de

A programmable particle counter for highly contaminated liquids

The S50DP online particle counter (photo) has an automatic dilution system that adds a programmable amount of solvent to a sample. The system's inner structural design ensures that the solvent and sample fluid are thoroughly mixed, resulting in homogeneity of the mixture and accurate, repeatable measuring results. Well-suited for use with fuel-containing free water and other highly contaminated liquids, the S50DP is equipped with a wear-resistant ceramic piston pump, which provides a constant flowrate of 25 mL/min at a pressure range of 0 to 6 bars. An integrated particle sensor measures sample fluids with a maximum concentration of up to 24,000 particles per mL. Hall 4.1, Stand A58 — *Pamas GmbH, Rutesheim, Germany*
www.pamas.de

Filtration and extraction systems for sensitive production areas

The CR Series of extraction and filtration systems (photo) is designed for use in cleanrooms and sensitive production areas. The CR Series' transfer-liner system alleviates the need for filter replacement inside a cleanroom. CR extraction systems are also offered with documented function tests and classification measurements related to the intended use of the device, for operational qualification. Customers can also receive instruction on the assembly and installation of a system. Hall 3.0, Stand D10 — *TBH GmbH, Straubenhardt, Germany*
www.tbh.eu

Laboratory chairs that adapt to repeated movements

The Labster chair was designed to automatically adapt to the special sequences of movements and sitting positions required by laboratory workers, providing freedom of movement, even during sustained and repetitive positions, such as sitting in a forward incline while pipetting. The ergonomic chair also upholds the high standards of hygiene demanded for S1 to S3 safety-class laboratories and Class 3 cleanrooms, as its seamless design prevents dust or contaminant collection on the chair itself. Hall 4.1, Stand J27 — *Bimos, a brand of Interstuhl Büromöbel GmbH & Co. KG, Meßstetten-Tieringen, Germany*
www.bimos.de ■

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Reduce risk for project success and performance

Emerson's Global Project Services Team collaborates with organizations to deliver project certainty

In a landscape of increasing technical complexity and fewer experienced resources, process industries are challenged to successfully execute projects. The impacts of missed deadlines, budget overruns, and unexpected scheduling hits can quickly spiral a project plan out of control.

As the largest project execution organization in the world, **Emerson Process Management** helps companies efficiently and effectively deliver projects by leveraging knowledge, experience, and technology. With Emerson's integrated project execution, users are implementing projects on time and within budget.

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The single source for emissions control

John Zink Hamworthy Combustion has been leading the industry for more than 80 years with continuous innovation and proven performance

Investment in facilities and experts is a vital part of **John Zink Hamworthy Combustion's** success. Their research and development centers make up the largest, most advanced testing complex in the industry, allowing engineers to push innovation, gain expertise and measure performance under real-world conditions. Ph.D. engineers use advanced computational fluid dynamics to solve turbulent fluid flow problems involving multiple-step chemical reactions and non-linear heat transfer. The company's researchers continually improve product performance and develop patented technologies that drive future solutions. Products include:

Flare systems: Advanced design and technologies set the standard for upstream, downstream and biogas flare industries.

Thermal oxidation: 3,500+ installed systems protect the environment by destroying up to 99.9999% of many hazardous wastes.

Process burners: Conventional low-NOx and ultra-low-NOx systems reduce pollution and maximize heating efficiency for ethylene and refining industries.

Boiler burners: Customized solutions accommodate variable fuels, emissions levels, boiler types and flame geometry for industrial steam generation, power generation and marine markets.

Flare gas recovery: Systems provide near-zero flaring, decreasing emissions and recovering flare gas to be re-used as fuel or feedstock for environmental control with an immediate return on investment.

Vapor control: 2,000+ vapor combustion and vapor recovery installations, utilizing technologies recognized as "Best Demonstrated Technology" and "Maximum Achievable Control Technology" by the U.S. Environmental Protection Agency.

Biogas: 700+ biogas flare systems in operation, including enclosed and elevated landfill systems, blower skids and the Ultra Low Emissions (ZULE) flare system, which delivers the highest destruction efficiency available with the lowest emissions.

Marine and offshore: Thousands of installations of gas and oil combustion systems. Specialized burner systems cover a variety of fuels and a range of applications including main and auxiliary boilers, thermal heaters and flare systems.

In addition, thousands of professionals have attended combustion and process courses at the John Zink Institute. The courses, taught by some of the world's most recognized engineers and educators, are held at the company's state-of-the-art test facility or on-site at customers' plant locations. **www.johnzinkhamworthy.com**

John Zink Hamworthy Combustion operates the largest, most advanced testing complex in the industry

Rapid growth for communications and blinds provider

Service Radio-Industrial Blind Solutions committed millions of dollars of additional inventory to its new Houston location for industrial blinds and communication products

Service Radio-Industrial Blind Solutions (IBS) is a premier supplier of two-way radios and industrial blind products to the industrial maintenance and construction industries. Thanks to its rapid growth, geographic coverage, state-of-the-art technology infrastructure, and commitment to service, Service Radio-IBS is able to respond swiftly to customer service and equipment needs. By employing the right people, training those people, operating as a team, and positioning the company strategically throughout the marketplace, Service Radio-IBS is able to provide an extremely high level of service.

What sets Service Radio-IBS apart in terms of communication technology is the fact that the company provides solutions to communications problems within industrial environments, not just the equipment needed to talk.

Everything the company does is built around the needs of industrial plants and contractors. Time is money to these customers, so the service component is critical. With the expansion of its inventories and locations, Service Radio-IBS now has close to 11,000 radios coast to coast. It also has the largest inventory of industrial blinds in the U.S., representing nearly 50,000 units strategically located in Louisiana, Los Angeles and Houston. The company also manufactures custom blinds for specific needs.

Utilizing Service Radio-IBS' products and services allows customers to finish projects on time, run their businesses effectively and save millions, the company says.

From its headquarters in Houston, Texas, Service Radio-IBS operates throughout the Gulf Coast and far beyond

www.srr-ibs.com

Predictive maintenance brings business benefits

Predictive maintenance for sensors protects against failure, increasing safety, uptime, reliability and profitability

Endress+Hauser's Liquiline platform – the Liquiline M CM42 two-wire transmitter for pH/ORP, conductivity or oxygen measurements; Liquiline CM44 multiparameter transmitter; and Liquiline CM44R DIN-rail device – supports all current and future Memosens sensors

The Memosens digital protocol from **Endress+Hauser** enables complete galvanic isolation of digital sensors and eliminates the cable and transmitters as an influence on the performance and perceived health of a sensor. Better data leads to better and more proactive maintenance decisions to protect against failure, reducing labor costs and increasing plant uptime, reliability and profitability.

Accurate pH measurement is critical for processes such as electrolysis. Memosens sensor technology can enhance pH measurements and substantially cut costs for chemical companies. One company was having trouble with analog pH measuring points due to high-impedance connections that were susceptible to faults and malfunctions, resulting in high maintenance expenses and low reliability and availability.

By fitting all measuring loops with digital Memosens technology, the company created a common platform for sensor data, allowing the measured value to be converted directly to digital signals inside the sensor. Since the sensors use inductive coupling, both for the signal transmission and power supply, this tackled the major problem of pH measurements at its roots. Memosens sensor electronics can be precalibrated in the lab under ideal conditions, so a sensor can be exchanged quickly and easily on site.

These smart sensors constantly deliver information on their state, so that probes are replaced only if necessary or cleaned and regenerated in the lab where possible. This predictive maintenance even increased safety by reducing the time personnel spent in the field. It triggered a continuous improvement process where all measuring points were gradually retrofitted with WirelessHART technology, allowing the facility to centrally analyze all sensor status information. **www.us.endress.com/memosens-predictive-maintenance**

Memosens digital sensors are galvanically isolated, thanks to inductive coupling for power and bidirectional data transmission, reducing moisture and corrosion problems associated with pH measurement

Traditional values with innovative pump designs

After 75 years Carver Pump Co. continues to supply pumps destined for some of the toughest industrial and military applications

Carver RS Series pump

Over three-quarters of a century, **Carver Pump Co.** has attained a reputation for creating value by providing pumps of premium quality with innovative designs for the automotive, chemical processing, mining, refining, power generation, general manufacturing and pulp/paper markets.

Boasting a product line known for its rugged construction features, a variety of horizontal and vertical end-suction pumps for multistage, axial split-case self-priming and API applications units are suitable for land-based, mobile and shipboard installations. With traditional values utilized in all phases of the operation to produce units of premium quality, new and innovative designs are routinely being developed to insure optimum performance.

Specifically designed for applications that require moderate to high discharge pressures, Carver has engineered a horizontal ring-section multi-stage pump known as the RS Series.

The RS Series is available in five sizes for flows ranging up to 1,400 GPM and pressures up to 1,500 psi. Featuring a product-lubricated radial sleeve bearing as standard and two matched angular contact bearings to handle the thrust, a low-pressure suction-side mechanical seal suits most requirements. Depending on the installation or application, these units are also available in a dual bearing/seal arrangement as an alternative design using ball bearings for both radial and thrust loads, plus a balanced mechanical seal for the discharge end.

Carver RS Series pumps are ideally suited for industrial and process applications including pressure boost systems, boiler feed, reverse osmosis, desalination and mine dewatering. **www.carverpump.com**

Plastic control valves handle corrosive chemicals

Collins 2-in. valves and actuators are specially designed to handle corrosive fluids – acids, bleaches, chlorine, pH control – and aggressive environments

Collins Instrument Company's line of economical 2-in. flanged plastic control valves handle corrosive liquids including hydrochloric acid, caustic, sulfuric acid, and many others. With bodies of either PVDF or polypropylene, these highly-responsive control valves are specifically designed for use with corrosive media and/or corrosive atmospheres.

Suitable for applications in numerous industries, including chemical, petrochemical, pulp and paper, and municipal, these valves are extremely corrosion-resistant, and feature fast-acting positioning (stroke rate approximately ½ in./s). They are available with a wide selection of trim sizes, in globe, angle, and corner configurations.

The differential-area piston eliminates the necessity for auxiliary loading regulators. All actuator parts apart from the integral positioner are molded of glass-filled, UV-inhibited polypropylene. Before shipment, the aluminum positioner and a portion of the cylinder are immersed in Dip Seal to provide atmospheric protection.

Plastic valves and actuators from Collins

The integral positioner eliminates the need for external linkages which are subject to corrosion and malfunctioning. Valves may also be furnished without a positioner for on/off applications.

Collins also offers a plastic pneumatic actuator. The combination of a plastic actuator and a plastic valve body provides an effective way to handle both corrosive materials flowing through the valve, and harsh environments that can attack the outside of the valve and actuator. Collins plastic control valve packages withstand salty marine atmospheres as well as industrial environments that are too corrosive for metal valves and actuators.

Collins actuators incorporate a unique internal locking ring to attach the cylinder to the yoke. A semicircular groove is machined inside the lower edge of the cylinder, and a matching groove cut in the yoke. When the yoke and cylinder are assembled, a flexible polypropylene rod is inserted into the groove through a slot in the side of the cylinder, securing the two sections together.

Along with its corrosion resistance the Collins control valve features a stem packing arrangement that virtually eliminates the problem of fugitive emissions, thereby protecting the environment.

Located on the Texas Gulf Coast in the town of Angleton, Collins Instrument Company has been serving the chemical and petrochemical industry for over 65 years. **www.collinsinst.com**

Spray lances and injectors custom engineered

BETE is a one-stop resource for drop-in custom spray lances, quills, injection lances, and chemical injectors

BETE is a true single-source supplier for spray nozzles, lances, piping spools and small vessels

For decades, refineries and chemical plants have counted on **BETE Fog Nozzle** to supply complete fabricated assemblies that can be custom designed starting with the spray nozzle. Beginning with the process conditions, BETE can recommend the most appropriate nozzle and then incorporate it into an assembly that meets all mechanical design criteria.

From the simplest to the most complex requirement, incorporation of client specifications is routine for BETE – as is design, fabrication, and inspection to code requirements, such as B31.3, B31.1, and Sec VIII-1. All design and fabrication work is performed at the same facility, with close coordination through all phases of the process to ensure all mechanical and performance requirements are met.

BETE Fog Nozzle provides custom retractable lances that allow a nozzle to be removed for inspection or service without taking the process offline. A retractable lance allows the operator to withdraw a nozzle, isolate it from the process, and then remove it completely for servicing – all while maintaining the integrity of the process boundary.

For smaller pipe sizes, retractable lances can be inserted and withdrawn manually. For larger sizes, or any size where automation or ease of use is required, BETE offers a robust retraction mechanism that effortlessly moves the lance. The mechanism is flexible in its configuration, allowing alternate electric, pneumatic, or hydraulic power sources to drive the unit.

Just as BETE can provide the lance on which the spray nozzle is installed, BETE can also provide the piping section into which the lance is installed. There are many benefits to single-sourcing all components related to the spray nozzle.

When all the work is done by one facility, there are no miscommunications between contractors about size, orientation, or location of the spray ports. The nozzles can be trial fit into the spool piece as part of the manufacturing process before leaving the factory, eliminating last-minute surprises.

BETE provides everything customers need, from the concept stage to on-site delivery, right down to the gaskets, studs, and nuts. BETE's Application Engineers can take a sketch, produce a recommendation and drawing of a proposed solution with the right custom fabrication designed to meet the required application. **www.bete.com**

Alleviate headaches caused by faulty steam traps

The TrapMan system from TLV uses a combination of ultrasonic and temperature measurement, backed up by a powerful database, to diagnose steam trap condition

One faulty steam trap loses an average of 11 lb/h (5 kg/h) of steam, notes steam specialist **TLV**. Faulty steam traps can cause a number of headaches for plant managers. There is the increased cost of maintenance, loss of plant efficiency, lowered manufacturing quality, and a greater safety concern for workers. TLV's TrapMan alleviates these pains by being the first diagnostic instrument to test a steam trap and make an automatic judgment of its operating condition.

TrapMan records both temperature and ultrasonic levels to identify dangerous blocked steam traps, or quantify steam loss. This combination improves site safety, reduces cost, and efficiently allocates maintenance expense.

The operator needs only to hold the probe tip on the trap for 15 seconds – then TrapMan collects and measures the trap's condition automatically. It compares the measurements against empirical test data of over 4,000 trap selections, and can store 1,600 individual tests.

Data is then uploaded to TrapManager database software for detailed analysis and reporting. The software can be configured to a user's needs, help predetermine inspection routes, and track and plan preventative maintenance. TrapManager is compatible with Windows XP/Vista/7.

The TrapMan is easy to train on, weighs only 2 lb and is intrinsically safe. The device eliminates variations in testing caused by human error, with its accuracy validated by Lloyd's Register. **www.tlv.com**

Properly-working steam traps save time and money, and increase safety

Optimize steam generation through level control

How to increase boiler efficiency with the Aurora magnetic level indicator

Steam is invaluable in a chemical plant. From cleaning to fermentation to chemical recovery, steam is incredibly versatile, and depending on the plant, large quantities may be required. The problem is that, when not properly regulated, steam generation can be a costly process. Liquid level control using the Aurora magnetic level indicator from **Orion Instruments** can increase boiler efficiency and prevent equipment damage.

Aurora combines high-visibility magnet-based local indication with Eclipse guided wave radar for accurate monitoring and control. Aurora's patented design allows for both of these technologies to operate totally independently of each other in a single chamber, providing unparalleled accuracy and safety with a small spatial footprint. An endless number of possible configurations and wide range of construction materials, including exotic alloys, plastics, and ceramics, make Aurora suitable for nearly every kind of application and process media. Furthermore, Aurora's rugged construction makes it a safer and more reliable alternative to sight glass gauges.

How can Aurora improve steam generation specifically? The key to maintaining efficiency within a boiler is keeping the liquid water at the correct level. When the water level is too high, the steam might not properly separate from the water. This leads to reduced boiler efficiency and unwanted moisture being carried into the process. When the level is too low, the boiler tubes risk becoming exposed, which can cause them to overheat and become damaged. Fortunately, Aurora's guided wave radar transmitter allows for real-time level control, ensuring the boiler operates continuously at an optimum water level, leading to reduced energy demands and lower maintenance costs.

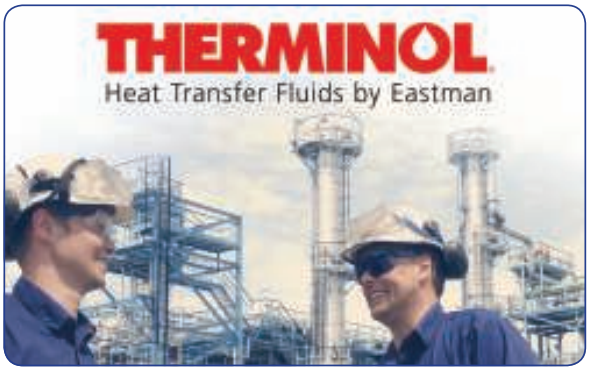
In addition to boilers, Aurora can help improve the operation of chemical reactors, deionization tanks, chemical injection skids and much more.

www.orioninstruments.com

Best of both worlds: The Aurora magnetic level indicator from Orion Instruments combines state-of-the-art guided-wave radar with high-visibility local indication for a level measurement and control solution that is reliable and versatile

Thermal fluid testing and analysis will pay off

Stop issues from becoming problems, with Eastman's Total Lifecycle Care program



Therminol heat transfer fluids are commonly used in offshore and onshore oil and gas processing, fractionation, refining, transportation, and recycling operations. Therminol 55, Therminol 59, Therminol 62, Therminol 66 and Therminol VP1 have successfully demonstrated low-cost, reliable, and safe performance in these applications for five decades.

When Eastman Therminol heat transfer fluids are used within suggested temperature limits in a well-designed and well-maintained system, they should provide years of excellent service. Thermal fluid in a heat transfer/coolant system can operate under demanding conditions. The fluid can experience degradation that results from thermal and possibly oxidative stresses. Frequent fluid testing and analysis can:

- extend fluid performance life;
- help protect equipment, saving maintenance costs;
- help avoid unplanned downtime;
- promote safety/fire prevention; and
- conform to insurance and fire safety recommendations that may impact insurance premiums.

Regular sampling, testing, and analysis of thermal fluid will also satisfy recommended practices published by insurance underwriters and fire prevention associations:

- NFPA 87, Recommended Practice for Fluid Heaters
- Global Asset Protection Services, GAP.7.1.5
- FM Global Datasheet 7–99 on Heat Transfer by Organic and Synthetic Fluids: "2.5.4.1 Test samples of the heat transfer fluid for impurities and/or degradation at least yearly."

Eastman provides heat transfer fluid testing and analysis to help detect fluid contamination, thermal degradation, moisture, and other issues that can help avoid corrosion, heat transfer decreases, start-up issues, blockages, fouling, freezing, pump cavitation, fire, and other performance issues.

Eastman provides complimentary Therminol fluid sample collection kits. Each kit includes a collection bottle, instructions on safe sampling, and shipping documents to return the sample to one of Eastman's in-house ISO-certified laboratories on four continents. There, expert lab technicians analyze each sample for key quality indicators, and send back a detailed report with suggestions for corrective action, if needed. The Eastman technical team will also answer any questions that may arise.

www.therminol.com

Delivering predictable results in E&C

Wood Group Mustang's proven solutions in engineering and construction minimize expenditures and help to optimize production

Wood Group Mustang provides clients with high-quality, high-value projects on time and within budget

Wood Group Mustang is a recognized leader in engineering, procurement, and construction management for the refining, chemicals, and polymers industries. The company's process engineers and project managers average more than 20 years in the process industry, with extensive knowledge of all project execution aspects for the industries they serve.

All designs are backed by a strong support team and the latest in project control and 3-D design tools. Wood Group Mustang has vast experience with the industry's leading technology licensors and providers while remaining technology-neutral, allowing the best solution to be delivered for the project at hand.

Projects are managed from concept through operation. Personnel have experience in most licensed and proprietary petrochemical, chemical and polymer processes, and regularly assist clients with the introduction of "first of a kind" technologies. In addition, they also offer comprehensive technical and economic studies, technology evaluation, experimental program design, pilot plant programs, and acquisition of physical and chemical property data aimed at delivering predictable results.

With a proven track record of providing solutions that minimize expenditures and optimize production, Wood Group Mustang contributes significantly to its clients' profitability. As an example, the company completed the largest expansion project in a particular client's history – on time, within budget and with zero safety incidents – increasing capacity of the facility by 45%.

In the U.S., Wood Group Mustang has offices in Texas, South Carolina, Colorado, North Dakota, Pennsylvania, and Louisiana. They also have numerous global locations to serve their clients. These locations all have on-site teams and virtual support, including the latest in project tools and shared resources of all disciplines.

http://marketing.woodgroupmustang.com/fullcircle/

A new twist in butterfly valve design

BYV Series butterfly valves from Hayward Flow Control feature advanced designs and materials to combine strength, corrosion resistance, and ease of operation

The revolutionary and patent-pending BYV Series Butterfly Valve from **Hayward Flow Control** incorporates the most advanced thermoplastic design and construction for butterfly valves in the industry today. Available in multiple thermoplastic materials from sizes 2 in. through 12 in. (DN50–300), the BYV Series has an extremely robust one-piece body construction while lighter weight than metal valves of equal size.

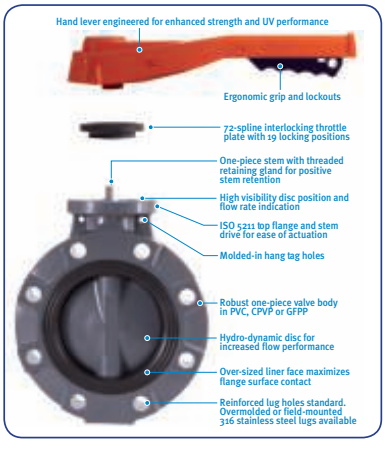
The revolutionary hand lever features a 72 spline interlock mechanism allowing for 19 stopping positions at every 5 degrees. The engineered hand lever material incorporates a UV inhibitor for enhanced performance in outdoor applications. The BYV also features reinforced lug holes, and can be ordered with overmolded 316 stainless steel lugs for dead end service or isolation needs. The BYV Series is available in ANSI 150 and DIN/EN PN10 flange patterns with a pressure rating of 150 psi / 10 bar at 70°F non-shock across all sizes and materials. Key features and benefits include:

- body and disc in PVC, CPVC and GFPP materials;
- EPDM, Viton or nitrile liners with oversized face;
- hydro-dynamic centric disc design for increased flow performance;
- one-piece 316 stainless steel stem with a threaded gland for positive stem retention;
- stem bearing and seal retainer for absolute stem positioning and sealing;
- ISO 5211 Top flange and stem drive;
- external disc position and flow indication;
- all sizes meet ANSI B16.10 / ISO 5752 narrow face-to-face dimensions.

Additional options include field-installable 316 stainless steel lugs, gear operators, pneumatic or electric actuators, manual limit switches, stem extensions, 2 in. square operating nut and chain operator for gearboxes.

BYV Series butterfly valves are made in Clemmons, NC, U.S., and backed by Hayward's exclusive two-year warranty.

Typical applications include chemical transfer and processing; waste and water treatment; aquatic and animal life support systems; mining; metal plating and surface finishing; marine; landfill and environmental infrastructure; and theme parks.



www.haywardflowcontrol.com

What you don't know can cost you

RedGuard explains some myths around blast-resistant buildings, which can be cost-effective as well as offering excellent protection to people and assets

Well-designed blast-resistant buildings are in no way inferior to traditional constructions, says RedGuard

A lot of myths still surround the use of blast-resistant buildings (BRBs) as traditional building replacements, *writes Tim Taton, North American Sales Manager with* **RedGuard**. Understanding these myths could save many thousands of dollars, not to mention lives.

Myth #1: Modular blast-resistant buildings (BRBs) are only available for lease.

When we pioneered the BRB industry, we offered only lease units, but we quickly learned that every application is different.

Fact: Our SafetySuites are permanent BRBs that can be purchased to meet specific operational needs for years to come.

Myth #2: BRBs are only for rush construction jobs.

Though SafetySuites can be erected in a fraction of the time needed for traditional buildings, they are a superior, permanent construction solution. They often cost less than traditional buildings, and do a better job of protecting personnel and resources.

Fact: BRBs are superior to traditional buildings for all construction projects.

Myth #3: BRBs lack the comforts and amenities of traditional buildings.

This myth is probably a holdover from the early days, when all of our engineering resources were devoted to creating the safest building in the world.

Fact: The inside of a SafetySuite is often indistinguishable from that of a traditional building, offering all the same amenities.

Myth #4: A blast pressure rating is the only important factor when specifying a BRB.

Blast pressure is a key part of the BRB design formula, but duration and response level ratings tell the real story of how a BRB will hold up to a blast. Some manufacturers claim a 5 or 8 psi rating, but with a high response level. This is virtually meaningless, as "high response" equates to high damage, with a high risk of casualties. Interior fittings are important, too, since a tough steel box, alone, does not make a safe BRB.

Fact: Blast pressure ratings, taken alone, can provide a misleading view of safety.

Myth #5: BRB design is still experimental.

While blast engineering is a comparatively new science, RedGuard has worked with some of the world's most respected authorities—and then performed blast testing under realistic conditions. A SafetySuite designed for a specific application will protect personnel during a blast event, at a fraction of the cost and construction time of a traditional building.

Fact: SafetySuites are built on proven engineering concepts that have been fully tested and proven safe. **www.redguard.com**

Process equipment designed and built with passion

Dipesh Engineering Works is a one-stop-shop for the design, manufacture, and supply of coded process equipment, plants, skids and systems

Producing equipment that delivers the precise process conditions necessary for complex chemical and petrochemical unit operations, with lifetime value, requires more than process and mechanical knowledge. It needs passion.

Such passion drives **Dipesh Engineering Works** not just to support its clients' goals and to meet the relevant process or engineering standards and specifications, but to go beyond these, providing the insight and innovative approaches that enable the equipment to deliver.

At every opportunity, engineers at Dipesh support clients in their objectives with passion. This approach enables Dipesh equipment to over-perform, for long periods and without problems. That's value, the company points out.

From small items to large, Dipesh Engineering Works delivers

Recently a petrochemical company had to augment its distillation facilities on a "war footing". The Dipesh team was in action right from the process design stage. All equipment items were closely integrated, so as to save time during erection and pre-piping. The project was completed quickly and on time, with no compromise in either equipment quality or plant performance.

Passion has taken Dipesh from being a basic manufacture of wooden vats, back in 1979, to a versatile and trusted process equipment manufacturer in India, working in virtually all metals, coatings and linings.

The company is already trusted by many multinationals and strives to be a globally acknowledged designer, manufacturer and long-term partner. **www.dipeshengg.com**

Increasing efficiency in the boiler room

Cleaver-Brooks is a complete boiler room solutions provider that helps businesses run better every day

Cleaver-Brooks manufactures the widest range of Nebraska-engineered, industrial watertube boilers and pioneered the world's highest-efficiency, ultra-low emissions burners. It offers the most advanced, integrated, boiler controls and burner management systems, and manufactures the broadest line of heat recovery systems in the world.

Watertube boilers: Designed to achieve maximum efficiency, reliability and low emissions. D-Style, A-Style, O-Style and Modular configurations are available. Sizes range from 10,000–1,000,000 lb/hr.

Natcom burners: Engineered for a specific application and furnace configuration. The company's advanced burner technology meets the most stringent NOx, CO, VOC and particulate emissions requirements.

Steam-ready Nebraska D integrated systems: Reduce the design-to-installation process by as much as 30%.

Heat recovery steam generators: Global provider of packaged, modular, field-assembled heat recovery steam generators (HRSGs) for specific applications.

Exhaust solutions: Freestanding stacks for customers with the most demanding applications. The engineering team creates efficient solutions based on exhaust combustion products, thermal and chemical conditions, corrosion effects, structural analysis, seismic calculations and vortex-induced load analysis.

Waste heat boilers: A complete selection of waste heat boilers to recover heat from process and generate steam, reducing the need for fired steam generation or recovery heat from solid, liquid or gaseous incinerators.

Selective catalytic reduction: Design and integrate selective catalytic reduction (SCR) into boiler and HRSG systems to reduce NOx emissions to single-digit levels. Available in a complete integrated system or with the burner in a retrofit application.

As the pioneer of packaged firetube and watertube boilers, Cleaver-Brooks is the only manufacturer in the world to offer an entirely integrated boiler room solution for any size application. **www.cleaverbrooks.com**

Cleaver-Brooks offers a fully integrated boiler room solution for any size application

Leading in process heat transfer technology

New developments built on a legacy of high-quality research forge the future for heat transfer research expert HTRI

Heat Transfer Research, Inc. (HTRI) has been conducting experimental studies in heat exchanger technology for more than 50 years. The company has expanded its renowned applied research program and state-of-the-art facility in Navasota, Tex. As part of an investment to meet the growing needs of nearly 1,500 corporate member sites, HTRI now offers computational fluid dynamics (CFD) testing, crude oil fouling studies, and AHRI Standard 400 Certification Testing.

HTRI conducts proprietary research for companies around the world and provides support, training, and specialized contract services to the processing industry. Data from rigorous computational studies are used to rapidly analyze heat exchanger problems and help prolong equipment life.

The company recently released an updated version of the acclaimed software, HTRI ***X****changer Suite*, which is considered the most advanced available for the design, rating, and simulation of heat exchangers. New capabilities include method updates and feature enhancements to several functions, including mechanical design, tube layout, and interoperability with other software packages. A new product to be announced in June will provide key performance indicators for shell-and-tube heat transfer equipment and support for single and two-phase refinery heat exchangers, reboilers, condensers, and preheaters.

X*changer Suite* uses an integrated graphical environment with modules for:

- shell-and-tube exchangers;
- jacketed-pipe and hairpin exchangers;
- plate-and-frame exchangers;
- plate-fin exchangers;
- spiral plate exchangers;
- fired heaters;
- air coolers and economizers;
- tube vibration analysis.

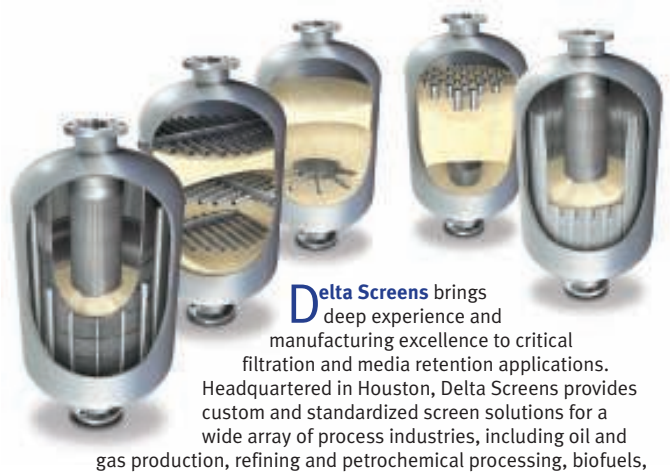
In addition to marketing its own products, the company is now the exclusive distributor for two new technologies which expand the options available to HTRI customers. One, Exchanger Optimizer software, helps processing plants maximize their resources and reduce heat exchanger costs using innovative cost analysis methods. The other, I2 Air Fluid Innovation, Inc., offers an eco-friendly approach to preventing bio-fouling in heat exchangers, heat pumps, and other heat transfer equipment.

HTRI's research facility in Navasota, Tex.

HTRI continues to move forward with an eye toward widening the boundaries of experimental research. This dedication to excellence assures customers of a high level of operating confidence in equipment designed with HTRI technology. **www.htri.net**

Advanced screening and filtration system solutions

Delta Screens supplies precision-made screening solutions for the filtration of process fluids, and also for retaining catalyst particles and other media within reactors



Delta Screens designed these screening systems for internal vessels used in refining and petrochemicals (photo, above)

Delta Screens brings deep experience and manufacturing excellence to critical filtration and media retention applications. Headquartered in Houston, Delta Screens provides custom and standardized screen solutions for a wide array of process industries, including oil and gas production, refining and petrochemical processing, biofuels, chemical processing, and mining and aggregates.

In refining and chemical processing, Delta Screens provides a broad selection of reactor screen internals for numerous applications. The company's screening and filtration products are engineered and manufactured to produce superior results in media retention, filtration, liquid-solid separation, and sizing and classifying granular materials.

Offering screening solutions for the world's most demanding environments, Delta Screens' expertise brings decades of screen and filtration experience, advanced manufacturing processes and cutting-edge technologies to ensure the highest quality screening products.

The company's state-of-the-art manufacturing facility produces a complete line of long-lasting and top-performing screens, engineered to withstand the rigorous working conditions of industrial operations.

Known globally for manufacturing screens for oil and gas production where extreme pressures and temperatures require the highest quality, Delta Screens is renowned for delivering screens that meet strict tolerances. That expertise lends itself to a broad array of industrial process applications.

Available in a variety of alloy options, Delta Screens' products are tracked from the moment raw materials arrive at the facility to the second a screen is shipped as part of a total quality assurance and quality control program designed to guarantee the highest possible screen performance and longevity.

The company is ISO 2001 compliant and provides complete QA documentation, manufacturing traceability reports, and in-process inspection reports immediately upon completion.

www.deltascreens.com

Verify plant performance to prevent costly breakdowns

Portable ultrasonic flowmeters can help to identify leaks, blockages and other process defects before they turn into serious incidents, says Badger Meter

Process plant managers need to be able to identify problematic equipment or system issues before they evolve into larger, more costly failures, notes flow measurement specialist **Badger Meter**.

Wherever liquids are being handled, irregular flowrates are a common indication of a leak, blockage, or other defect. In many cases, flowmeters are installed permanently into pipelines, but this is not always the case. Where permanent meters are not installed, or where systems are frequently altered to accommodate changing processes, it's important for plant maintenance personnel to have the flexibility to quickly monitor flow without breaking into the pipeline and holding up production.

An ideal solution is to use non-invasive ultrasonic flowmeters, which are easily clamped onto the outside of pipes without interfering with process flow. Badger Meter's Dynasonics DXN portable flowmeter is capable of measuring a wide range of fluid types, from water to slurries, using ultrasonic sensors set to either Doppler or transit-time modes.

With an intuitive Windows-based touch-screen interface, technicians can store multiple custom site parameters to allow for quick set-up at different monitoring locations. Measurement data can also be logged and saved offline, helping operation personnel to recognize long-term performance trends.

Using a Dynasonics DXN portable flowmeter can help companies control maintenance and lost production costs by quickly and easily identifying irregularities in process flow.

Verifying process flows with a Dynasonics DXN flowmeter (inset)

Badger Meter is based in Milwaukee, Wis. The company manufactures a variety of flow instrumentation and control products for water, air, steam, oil, other liquids, and gases. Operating principles include electromagnetic, positive displacement, turbine, ultrasonic and variable-area flowmeters, plus small control valves. The portfolio also includes brands such as Blancett, Hedland, Preso, Cox, and Research Control valves.

www.badgermeter.com/dxn

Minimizing downtime, maximizing performance

Team Industrial Services offers a wide range of specialized services that allow plant turnarounds to be conducted quickly, effectively, and above all safely

Turnarounds allow for necessary maintenance and upkeep of operating units and are needed to maintain safe and efficient operations. Founded in 1973, **Team Industrial Services** is the worldwide leader in minimizing equipment and asset downtime, providing a number of services to assist with turnarounds and outages including on-line maintenance, inspection and repair. The company provides critical services to its customers that enable them to maintain and operate their facilities and equipment in a safe and productive manner.

Team's line of specialized industrial services includes bolting/torquing, concrete repair, emissions control, exchanger services, field machining, fitness for service, heat treating, hot tap/line stop, isolation test plugs, leak repair, manufacturing/engineering, mechanical integrity, NDE/NDT inspection, project services, specialty welding, turnkey tank program, valve insertion, and valve repair.

Team employs only the best, most qualified technicians to ensure each and every job is completed to the highest standards every time. The company maintains management systems and documented work procedures designed to assure compliance with all applicable laws, regulations and internal requirements, as well as to facilitate the continuous improvement of its processes, products, and personnel. The highest priority at Team is the safety of employees, clients, and other contractors. The company is committed to safety excellence and strives daily for zero injuries and incidents.

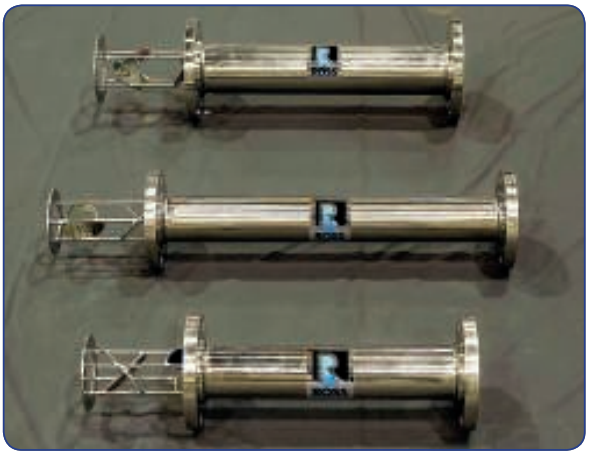
Today, Team is rapidly growing its global footprint across a wide range of industries – with service locations in five continents. The company recognizes that its global success is ultimately measured by its customers' trust and confidence, which can only be earned through continuing outstanding service. Team's trained and certified technicians are available worldwide 24/7/365. From single part repair to turnarounds and shutdowns – planned or unplanned – Team has the training, experience, technology and know-how to deliver high-quality maintenance, inspection, and testing services anytime, anywhere. **www.TeamIndustrialServices.com**

Safe working methods are always a priority for Team personnel

A classic mixing tool for the petroleum industry

Ross LPD Static Mixers are rugged, reliable devices for inline mixing at minimal pressure loss, with applications throughout the oil and gas industry

Ross Low Pressure Drop (LPD) Static Mixers are used throughout the oil and gas industry for turbulent-flow mixing applications.



Shown are removable LPD mixing elements supplied with a retainer ring which goes between two mating flanges to keep the mixer from spinning or moving downstream

These heavy-duty low-maintenance devices serve in continuous operations where high performance and accuracy are required, such as on-line water determination of crude oil; dosing of various additives into gasoline; blending different kinds of fuel oils; gas-gas blending; and pipeline reactions, among others.

Static mixers have no moving parts and the energy for mixing is available in the form of pressure. Pressure loss – a natural consequence of static mixing – sometimes becomes the deciding factor in mixer selection. The LPD Static Mixer remains a classic choice for many inline blending requirements due to its simple and durable design capable of uniform mixing with little pressure loss. The mixer elements consist of semi-elliptical plates carefully positioned in series to split and rotate the product 90 deg. in alternating clockwise and counterclockwise directions.

LPD mixers in diameters from 1 in. through 2.5 in. are welded to a central rod, while larger elements are welded to four outside support rods for maximum rigidity and stability. Units as large as 48 in. diameter can be supplied as stand-alone mixer elements or as modules complete with a mixer housing and injection ports.

Established in 1842, Ross is one of the oldest and largest mixing equipment companies in the world. Ross mixing, blending, drying and dispersion equipment is used throughout many industries in the manufacture of foods, adhesives, electronics, coatings, cosmetics, pharmaceuticals, plastics and composites.

www.staticmixers.com

Product Showcase

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Company ____________________

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City ____________ State/Province ____________ Zip/Postal Code ____________

Country\ ____________ Telephone ____________ Fax ____________

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

FREE PRODUCT INFO

(please answer all the questions)

YOUR INDUSTRY

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

JOB FUNCTION

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

EMPLOYEE SIZE

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

YOU RECOMMEND, SPECIFY, PURCHASE

(please circle all that apply)

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

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

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May 2015; VOL. 122; NO. 5

Economic Indicators

2013 2014 2015

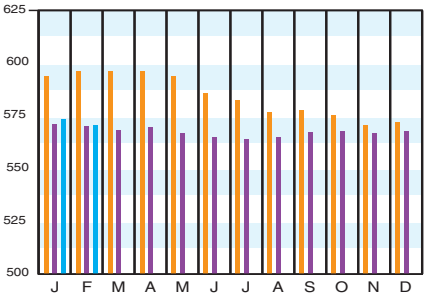
Download the CEPCI two weeks sooner at www.chemengonline.com/pci

CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957-59 = 100)	Feb. '15 Prelim.	Jan. '15 Final	Feb. '14 Final
CE Index	570.6	573.1	574.9
Equipment	691.8	694.8	697.6
Heat exchangers & tanks	631.4	636.4	637.2
Process machinery	673.8	663.5	663.9
Pipe, valves & fittings	863.2	868.9	881.9
Process instruments	404.0	407.2	412.9
Pumps & compressors	950.9	948.7	931.7
Electrical equipment	513.8	513.9	515.5
Structural supports & misc	748.0	758.0	759.6
Construction labor	319.1	321.5	321.5
Buildings	545.4	546.9	541.4
Engineering & supervision	320.1	320.1	322.8

Starting with the April 2007 Final numbers, several of the data series for labor and compressors have been converted to accommodate series IDs that were discontinued by the U.S. Bureau of Labor Statistics

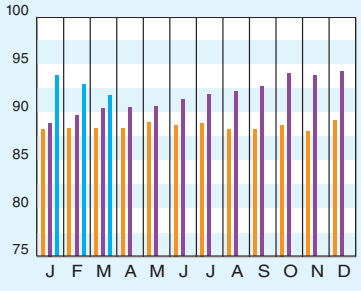
Annual Index:
2007 = 525.4
2008 = 575.4
2009 = 521.9
2010 = 550.8
2011 = 585.7
2012 = 584.6
2013 = 567.3
2014 = 576.1



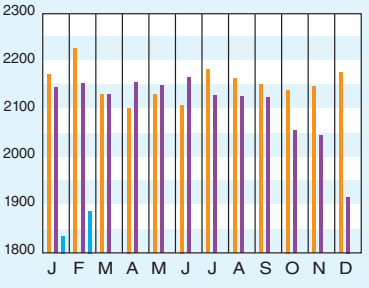
CURRENT BUSINESS INDICATORS

	LATEST	PREVIOUS		YEAR AGO
CPI output index (2000 = 100)	Mar.'15 = 91.8	Feb.'15 = 92.4	Jan.'15 = 92.7	Mar.'14 = 90.0
CPI value of output, $ billions	Feb.'15 = 1,887.9	Jan.'15 = 1,834.4	Dec.'14 = 1,924.3	Feb.'14 = 2,154.1
CPI operating rate, %	Mar.'15 = 76.8	Feb.'15 = 77.3	Jan.'15 = 77.6	Mar.'14 = 76.0
Producer prices, industrial chemicals (1982 = 100)	Mar.'15 = 245.4	Feb.'15 = 241.8	Jan.'15 = 246.4	Mar.'14 = 291.1
Industrial Production in Manufacturing (2002=100)*	Mar.'15 = 101.2	Feb.'15 = 101.1	Jan.'15 = 101.3	Mar.'14 = 98.8
Hourly earnings index, chemical & allied products (1992 = 100)	Mar.'15 = 157.4	Feb.'15 = 157.5	Jan.'15 = 157.6	Mar.'14 = 156.7
Productivity index, chemicals & allied products (1992 = 100)	Mar.'15 = 107.3	Feb.'15 = 107.8	Jan.'15 = 108.2	Mar.'14 = 106.7

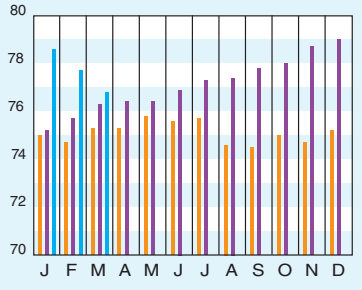
CPI OUTPUT INDEX (2000 = 100)



CPI OUTPUT VALUE ($ BILLIONS)



CPI OPERATING RATE (%)



*Due to discontinuance, the Index of Industrial Activity has been replaced by the Industrial Production in Manufacturing index from the U.S. Federal Reserve Board.
Current business indicators provided by Global Insight, Inc., Lexington, Mass.

CURRENT TRENDS

The preliminary value for the February 2015 *CE* Plant Cost Index (CEPCI; top; most recent available) declined from the previous month's value and now stands at 0.7% lower than the corresponding value from a year ago. The Equipment, Construction Labor and Buildings subindices dipped slightly from January, while the Engineering & Supervision subindex held steady. Meanwhile, the Current Business Indicators (middle) showed an increase in CPI value of output for February, but the level is still below that of one year ago.

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