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February 2016

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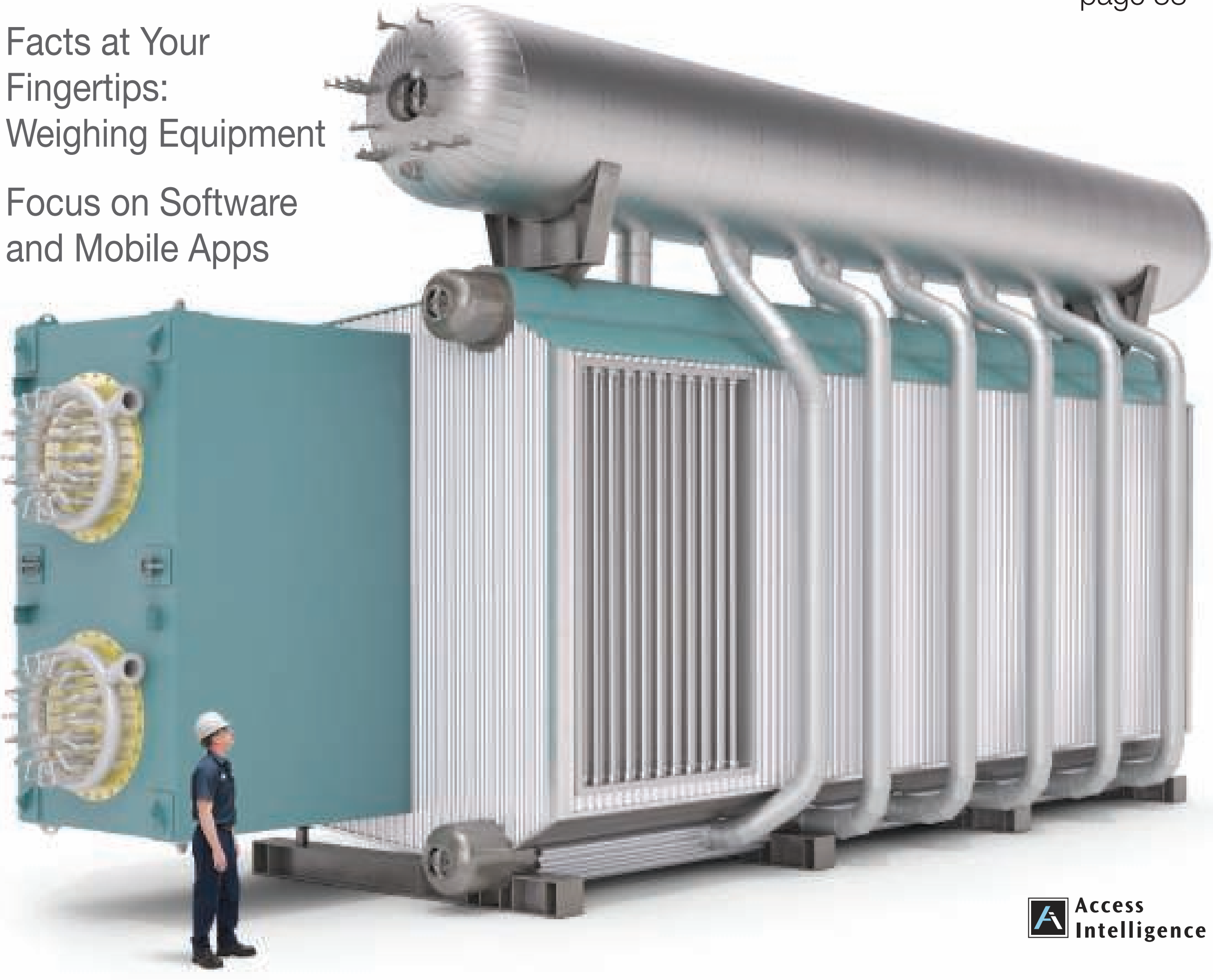

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In the News

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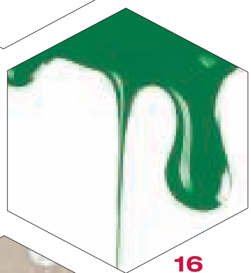

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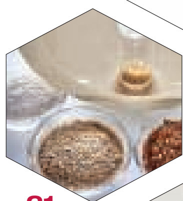

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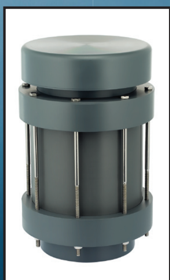

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Editor's Page

Ensuring a water supply

This past December marked the dedication of the largest seawater desalination plant in the U.S. The Claude "Bud" Lewis Carlsbad Desalination Plant, named for the former Carlsbad, Calif. mayor who was instrumental in choosing the location, is designed to provide 50 million gallons of water per day to San Diego County from the Pacific Ocean, to help minimize the area's vulnerability to drought. This $1-billion project includes the desalination plant that uses reverse osmosis (RO), a 10-mile pipeline and upgrades to facilities to distribute the water.

As California confronts its fifth year of drought conditions, water-shortage concerns are at the forefront of the public's attention. A recent poll by the Hoover Institution (Stanford, Calif.; www.hoover.org) asked 1,800 Californians to prioritize policy concerns facing the state. Dealing with the state's water problems was a top finisher. And, in another question, more than half said they would vote to end a high-speed rail project and use the unspent money on water-storage projects instead.

The Carlsbad project may well serve as an example for future desalination projects in the U.S. There is already a proposal to build another facility of the same capacity in Huntington Beach, Calif. (www.hbfreshwater.com).

A global concern

While the Carlsbad mega-project is the largest seawater desalination plant in the Western Hemisphere, it is not the largest in the world. The Sorek Desalination Plant in Israel, which also uses RO technology, makes that claim, with a capacity of about 165 million gallons of water per day. The Sorek facility was commissioned in 2013.

Water scarcity is a global issue, and technology plays a key role in finding ways to ensure water supplies where needed. For example, according to the Carlsbad Desalination Project website (www.carlsbaddesal.com), "dramatic technological improvements have made desalination much more cost-effective." Specifically, the longer lifetimes, energy efficiency and lower cost of RO membranes as compared to just 10 years ago were cited as cost saving advances.

The contributions of engineers and scientists are vital to finding viable ways to help alleviate water shortages. Water conservation, reuse and wastewater treatment are all important. And only through continuing work will further advances to help make desalination more economical be possible

Some of the most recent technologies related to water as reported in *Chemical Engineering* include development of an organosilane-based membrane for desalination (January 2016, p. 7); "switchable solvent" technology for forward osmosis (November, 2015, p.13); a new gas-transfer membrane for biological wastewater treatment (November, 2015, p. 7); and several new wastewater-treatment studies as reported in this issue (pp. 8–9).

Inside this issue

Our February issue covers a wide variety of topics, including our cover story on boilers (pp. 38–47), a news story on advances in paints and coatings (pp. 16–20), an article on managing small- and medium-sized projects (pp. 54–57), a feature report on materials selection for machining processes (pp. 48–53) and much more. We hope you enjoy it. ■

Dorothy Lozowski, Editor in Chief

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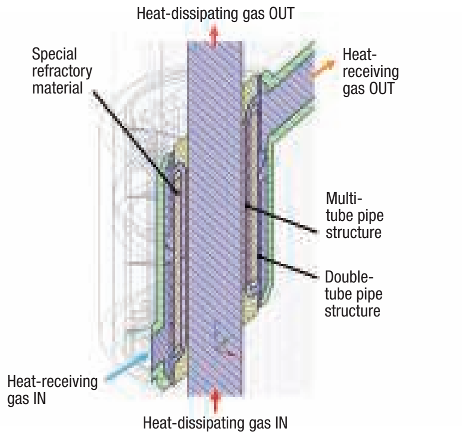
A very efficient heat exchanger for very hot applications

At the end of last year, Mino Ceramics Co. (Nagoya City, Japan; www.mino-ceramic.co.jp) began shipping its first commercial high-temperature heat exchangers, which were developed in a project by Thermal Management Materials and Technology Research Assn. (TherMAT, Tokyo, Japan; www.thermat.jp). Developed with support from the New Energy and Industry Technology Development Organization (NEDO; Kawasaki City, Japan), the heat exchangers can be operated at temperatures as high as 1,300°C, with a heat-recovery efficiency nearly three times higher than existing technology, making them suitable for utilizing waste energy from industrial furnace applications.

In addition to incorporating materials that are both highly heat resistant and durable, the new heat exchangers (diagram) feature a hybrid structure of double and multiple cylindrical tubes to enhance surface area and thus, the heat-recovery performance. At a temperature of 1,300°C, the heat-recovery performance of the new heat exchangers is 18–24%, which is almost three times higher than the 5–7% achieved by existing high-temperature exchangers.



Mino Ceramics is planning to further enhance the performance of the heat exchangers for temperatures up to 1,500°C, and develop the market for recovering waste heat in industrial applications. NEDO also continues to support the development of technology for the effective utilization of waste-heat sources, such as fine ceramics fabrication.

Alkylate process featuring a solid-acid catalyst can use multiple feedstocks

A recently announced process based on a novel solid-acid catalyst is effective at producing high-quality alkylate from a variety of feedstocks, including methanol. Technology developer Exelus Inc. (Fairfield, N.J.; www.exelusinc.com) says its technology converts methanol and mixed-butanes to high-octane alkylate. The process, known as M2Alk, is designed to enable petroleum refiners to process lighter natural-gas-derived feeds. At current U.S. methanol and butane prices, M2Alk produces high-octane alkylate well below current gasoline prices.

Alkylate, a major component of modern gasoline that burns cleanly and reduces "knocking" in engines, is conventionally produced by reacting isobutane contained in mixed butanes with C3 to C5 olefins using liquid-acid catalysts, such as HF or H_2SO_4. Because of the large volumes of liquid acids required and the associated safety and environmental risks, considerable R&D has been aimed at developing solid-acid catalysts for alkylation.

Exelus' technology uses a proprietary solid-acid catalyst, called ExSact-E, that facilitates the reaction of isobutane with a variety of light olefins, including ethylene, which cannot be alkylated with liquid-acid catalysts. The ExSact-E catalyst is an engineered zeolite catalyst that has optimized acid sites, and an innovative pore structure that minimizes deactivation of the catalyst by coking, according to Mitrajit Mukherjee, president of Exelus. The catalyst has much better stability than conventional zeolite catalysts, the company adds, allowing the use of a fixed-bed reactor. The catalyst also eliminates the formation of acid-soluble oils, which is typical with liquid-acid catalysts, Mukherjee says.

The catalyst is easily regenerated using hydrogen, and can be used for alkylation with several feedstocks under a variety of conditions. Mixed butanes are components of natural gas liquids, while light olefins come from a variety of sources, including from fluid-catalytic cracking (FCC) units at petroleum refineries, as well as from methanol, bioethanol and steam crackers.

Edited by:
Gerald Ondrey

BIO-HYDROGEN

Scientists at Indiana University (IU; Bloomington, Ind.; www.iu.edu) have created a highly efficient biomaterial that catalyzes the formation of hydrogen from water. The biomaterial could be used to produce H_2 or generate power from H_2 in a fuel cell.

Using methods they developed, the IU scientists, led by Trevor Douglas, inserted the enzyme hydrogenase into a protein shell (capsid) from bacteriophage-P22, a virus that infects bacterial cells. The resulting biomaterial is more efficient than the unaltered enzyme and is produced through a simple fermentation process at room temperature. The biomaterial is potentially far less expensive and more environmentally friendly to produce than other materials currently used as fuel-cell catalysts, such as platinum metal. Upon encapsulation in the capsid, the enzyme gains significantly greater resistance to breakdown from chemicals in the environment, and it retains the ability to catalyze at room temperature.

"No one's ever had a way to create a large enough amount of this hydrogenase, despite its incredible potential for biofuel production. But now we've got a method to stabilize and produce high quantities of the material — and enormous increases in efficiency," says Douglas.

H_2 FROM FORMIC ACID

In Japan, there are three major hydrogen-carrier systems being developed for future hydrogen-fuel filling-station applications that are based on either methylcyclohexane, ammonia or liquefied H_2. For example, methycyclohexane stores H_2 when converted

(Continues on p. 8)

Note: For more information, circle the 56-digit number on p. 62, or use the website designation.

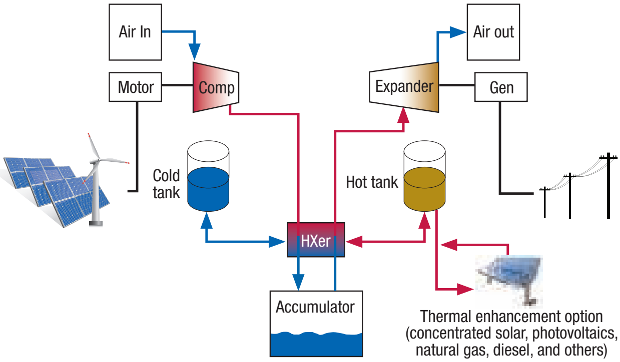
to methylcyclohexane, and then releases H_2 when needed. Now, a promising alternative H_2 carrier, based on formic acid, is being developed by the group of Hajime Kawanami at the Research Institute for Chemical Process Technology, National Institute of Advanced Industrial Science and Technology (Sendai City, Japan; https://unit.aist.go.jp/cpt/034_cpt-mfc_en.html). The researchers have developed a catalyst, based on an iridium complex, that selectively decomposes formic acid at a temperature of less than 100°C, to produce H_2 at very high pressure (greater than 120 MPa). This temperature is significantly lower than the 200°C needed to generate H_2 from cyclohexane-based H_2 carriers, and the formation of pressurized H_2 is advantageous in refueling vehicles.

The catalyst has a high turnover frequency (1,800 h^{-1}) at 40 MPa, and generates H_2 and CO_2 at a very fast rate (1.2 MPa/s per gram of metal). The H_2 can easily be recovered by a simple gas-liquid separation at –10°C to give 85% H_2. Further cooling to –50°C removes the remaining CO_2, and the product H_2 has less than 6 parts per million (ppm) by volume CO.

WATER PURIFICATION

University of Cornell researchers, led by Will Dichtel, associate professor of chemistry and chemical biology, have invented a porous form of cyclodextrin that adsorbs pollutants from wastewater at rates vastly superior to traditional activated carbon — 200 times greater in some cases. This fast adsorption rate means the material has the potential for very low energy, flow-through water purification applications, says Dichtel. The cyclodextrin-containing polymer has a cup shape, which gives it a large surface area. It features easier, less-expensive regeneration, so it can be reused many times with no loss in performance, says Cornell. ❒

Using air and hydrostatic pressure to store energy underwater



Consisting of a land-based mechanical facility and underwater pipelines and accumulators, the underwater compressed-air energy-storage (UCAES) system from Hydrostor Inc. (Toronto, Ont., Canada; www.hydrostor.ca) takes electricity (potentially excess solar or wind energy) and uses it to run a compressor, which pressurizes atmospheric air, while also enabling the capture of the heat of compression. Once the pressure of the air is equal to the hydrostatic pressure of the nearby body of water where the accumulators are located, the air is sent through the pipeline to the accumulators, where it is stored until the UCAES system needs to produce energy. At this time, a valve is opened, allowing the weight of the water to push the air back through the pipeline to a network of heat exchangers, an expander and eventually a generator. Since the direction of airflow is controlled by simply opening a valve, this allows for "black start" — the system can be started without using additional power from the grid.

The systems are designed for a specific application's needs. A balance between water depth and the installation's distance from land is key in selecting the best sites and sizing the compressor and turbo-expander, explains Hydrostor CEO Curtis VanWalleghem. The systems use standard 12-in. pipelines, and multiple lines can be installed in parallel based on pressure-drop requirements. The amount of storage capacity required determines the required number of accumulators, which are available in either a flexible, balloon-like version or a rigid cement version. The mechanical nature of this energy-storage technique leads to a much longer lifetime and lower costs than battery-based technologies, says VanWalleghem

After four months of construction, the company commissioned its first installation of a UCAES system in Toronto in November 2015. In the coming months, Hydrostor expects to announce a partnership with a global engineering, procurement and construction (EPC) company.

Removing harmful metals from wastewater with crab shells

Copper and cadmium exist naturally in the environment, but human activity can increase their concentrations to a point where they become a health hazard. Conventional wastewater treatment to remove those metals includes chemical precipitation, coagulation, flocculation, ion exchange, membrane filtration, activated carbon, and the use of carbon nanotubes. However, naturally occurring biosorbents can clean up contaminated water at the same efficiency, and with little impact on the environment and on human health.

Crab shells from *Scylla serrata* (mud crab) proved to be a good biosorbent for removing copper and cadmium from industrial wastewater by researchers from the Universiti Putra Malaysia (Serdang, Malaysia; www.upm.edu.my). The researchers chose crab shells due to their abundance and ready availability as waste products. The crushed crab shells were able to remove up to 94.7% of copper (5 mg/L initial concentration), and 85.1% of cadmium (1 mg/L initial concentration). The conditions (pH = 6, T = 25°C) closely matched the wastewater effluent characteristics from industrial mining and metal refining.

Crab shells consist of calcium carbonate and protein (29.19%), ash (40.60%), lipids (1.35%), and chitin (26.65%) on a dry weight basis. The researchers say the calcium carbonate and chitin in the crab shells are found to be the most effective in removing heavy metals, especially copper and lead. This is because calcium carbonate forms strong copper-carbonate and lead-carbonate bonds when reacting with copper and lead, while chitin acts as an adsorbent for precipitation in the presence of those metals, they say.

A ‘greener’ route for making red pigments

Early this year, Lanxess AG (Cologne, Germany; www.lanxess.com) will start production of bright red iron-oxide pigments at its Ningbo, China production site. The production facility will utilize — for the first time — the Ningbo Process, a highly sustainable production process that the company has developed in a test reactor at its Krefeld-Ürdingen, Germany site. Compared to the traditional Penniman production process, which is already widely used in China for making yellowish-red pigments, the new Lanxess technology ensures substantial improvements in terms of sustainability. The new plant for iron-oxide red pigments in Ningbo is being designed for an initial synthesis capacity of 25,000 m.t./yr.

The Penniman process is one of four routes that are used for making pigments of various shades of red. The Penniman red process produces particularly yellowish-red pigments. However, the process generates oxides of nitrogen (NOx) and wastewater that contains dissolved ammonium nitrate. While developing a “cleaner” and more sustainable process, Lanxess also discovered that the conventional route also produced significant quantities of nitrous oxide — a greenhouse gas (GHG) with a global-warming potential that is 300 times higher than that of CO_2, as well as being an ozone-depleting compound.

In the conventional process, hematite seeds are first produced by the reaction of scrap iron with HNO_3 at a temperature of over 90°C. The hematite seeds, together with the scrap iron and ferrous nitrate, are then developed into pigments at temperatures of 70–95°C under aeration. After the pigments are formed, they are filtered, washed, dried and (if required) milled to the desired size.

The Ningbo Process ensures NOx emissions are reduced by over 90%, while also reducing energy consumption by 80%. Significantly less $Fe(NO_3)_2$ is required, which minimizes the amount of dissolved nitrates in the wastewater. Residual NOx is removed in a nitric-acid-recovery plant, with the recovered acid reused in the process. The N_2O, which cannot be removed by scrubbing, is catalytically converted into N_2, O_2 and H_2O. Heat from this exothermic reaction is recovered and used in the process. Finally, a multistage wastewater-treatment process, including sedimentation, biological denitrification, ultrafiltration and reverse osmosis, produces water that can be reused as process water.

Coral enhances the removal of mercury from wastewater

A convenient route for the fabrication of a bio-mimetic, coral-like nanoporous γ-Al_2O_3 with a higher capacity to adsorb Hg(II) in aqueous solution than those of commercial Al_2O_3, has been reported by a research group from Anhui Jianzhu University (Hefei City, China; www.ahjzu.edu.cn), the Chinese Academy of Sciences (Hefei, China; www.cas.ac.cn), and Monash University (Melbourne, Australia; www.monash.edu).

Generally, nanosized γ-AlOOH (boehmite) or γ-Al_2O_3 adsorbents have been used to remove heavy metals, such as mercury from water due to their high surface area and the existence of rich adsorption sites. However, those adsorbents tend to aggregate in solution during the adsorption process, resulting in a decrease of adsorption efficiency. Also, they require centrifugation to separate the heavy metals from water, which limits their large-scale industrial application. Coral-like adsorbents might overcome this problem due to their hierarchical micro/nanostructure. The microsized units are composed of curled nano-sized units that can resist aggregation, maintain high exposed surface area, and they can be easily separated, leading to high adsorption efficiency. Therefore, coral-like aluminum-based materials should be high efficiency adsorbents.

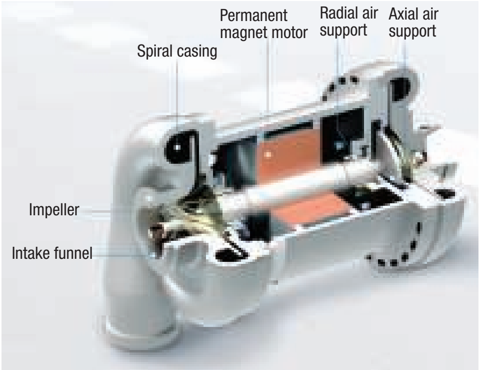
The researchers fabricated the nanoporous γ-Al_2O_3 by annealing coral-like γ-AlOOH based on an ethylene-glycol driven self-curled assembly process. In this process the ethylene-glycol works as a capping agent for the self-curled process of the layered structure of γ-AlOOH nanoplates, and also as a driving force for their assembly through a charge shielding effect.

The γ-Al_2O_3 unit (approx. 1.5 µm) obtained by the group is composed of curled porous (2.5-nm-dia. pores) γ-Al_2O_3 nanoplates. The material obtained has a Hg(II) removal capacity 2.5 times higher than that of commercial Al_2O_3 nanoparticles and 2.7 times the removal capacity of hollow structured γ-Al_2O_3 prepared without ethylene glycol.

Oil-free compressed air at a fraction of the cost

The recently commercialized high-speed turbo (HST) compressors from BOGE Kompressoren Otto Boge GmbH & Co. KG (BOGE; Bielefield, Germany; www.boge.de) produce 100% oil-free (Class 0) compressed air at the highest degree of efficiency and with minimal maintenance effort, according to Matthias Eichler, head of Branding and Marketing Services. The HST compressors incorporate a number of design features that result in a "radical reduction" in the number of components compared to conventional compressors. As a result, BOGE was able to reduce the total costs, compared to oil-free screw compressors, by up to 30%, says Eichler.

The new compressors (diagram) are driven by a permanent magnet motor, which is characterized by a very high energy density. Airfoil bearings are used — for the first time — in the drive shaft, which enables operation at extremely high speeds (up to 120,000 rpm). Titanium impellers, located at the end of the motor shaft, rotate at high speeds and set the intake air in motion. Thanks to the geometrical design of the impeller in conjunction with the diffuser and the spiral housing, the kinetic energy is effectively converted to pressure energy. A sophisticated cooling concept ensures effective cooling of the air after each compression stage, and integrated frequency inverters allow the volume flowrate to be infinitely adjusted to the demand for compressed air.



Other features of the HST compressor include the following: Only one movable part per drive motor is installed, as well as significantly fewer bearings and seals. There is no fan motor, gear unit, lubrication system or oil pump. As a result, the footprint of the HST compressors is half that of alternative oil-free screw compressors, and the weight is also reduced by two thirds, says Eichler.

Three models will be available with a standard pressure of 7.5 bars. Boge began serial production of the HST 55 (7.97 m^3/min) in November 2015, and will follow later this year with the HST 110 (17.97 m^3/min) and the HST 220 (36.57 m^3/min).

Polymer-reaction monitoring

There are many critical parameters that are important to monitor and measure in industrial polymer reactions, including molecular weight, viscosity and residual monomer concentration. Typically, polymer reactions are characterized offline and intermittently in a quality-control laboratory, or via inferential models and data simulation from spectroscopic probes. Now, a new technology that allows for direct, online, continuous monitoring of polymerization reactions has been commercialized by Advanced Polymer Monitoring Technologies, Inc. (APMT; New Orleans, La.; www.apmtinc.com). APMT's product, called Automatic Continuous Online Monitoring of Polymerization Reactions (ACOMP), comes after 18 years of research at Tulane University (New Orleans, La.; www.tulane.edu), much of it funded by large chemical companies, says APMT CEO, Alex Reed. Interest in the technology has been diverse across many industry sectors, including both producers of specialty and commodity polymers, as well as natural products producers, explains Reed, emphasizing that "the ability to make these types of measurements on fundamental polymer properties online and in near realtime allows manufacturers to more efficiently control the process."

The ACOMP technology employs a continuous sampling and conditioning system that extracts a small stream of polymer from the process. The sample is diluted and sent to multiple analytical-grade detectors for continuous, cross-correlated, non-chromatographic measurements, which yield a complete picture of the most important reaction characteristics at each point in time. Data analysis and reporting functions are built into ACOMP's software platform. The product has been vetted on batch, semi-batch and continuous reactors in both aqueous and organic solvents for a wide variety of synthetic and biological polymers, says Reed.

APMT collaborated with various partner companies in industrial instrumentation and automation to commercialize ACOMP. The company is currently working to integrate ACOMP data into predictive-control models to provide automatic feedback-control software. The company is also investigating the use of ACOMP for chromatography-free online determination of molecular-weight distributions. To accompany the industrial ACOMP model, APMT is developing a version specific to research-and-development (R&D) applications. The company also has a second product involving high-throughput light scattering, currently in growing use for monitoring the stability of biologic drug formulations in the pharmaceutical industry, including potential process analytical applications in that industry.

These CeO_2 nano-rods store a lot of O_2 at low temperatures

Automobile catalytic converters contain cerium-based co-catalysts to enhance the overall effectiveness of the converter by absorbing and releasing oxygen to convert CO into CO_2. Existing emission control systems typically use CeO_2-based materials, such as solid solutions of ceria and zirconia, which deliver good performance at high temperatures, but their oxygen storage capacity (OSC) deteriorates at temperatures below 300°C. To overcome this drawback, researchers from the group of Naoki Asao at Tohoku University (Sendai City, Japan; www.wpi-aimr.tohoku.ac.jp/asao_labo) have developed a process to fabricate fine nano-rods of CeO_2 that have a high OSC at temperatures below 200°C.

To make the nano-rods, a Ce-Al precursor is first "corroded" by a selective leaching process, which uses an alkaline solution under mild conditions to selectively leach away the Al and oxidize the Ce, followed by rapid quenching. The resulting CeO_2 nano-rods have diameters of 5 to 7 nm and specific-surface areas of more than 200 m^2/g. They exhibit an OSC of 156 µmol O_2/g at 200°C (81 µmol O_2/g at 100°C), which is five times greater than existing nano-cube systems at 200°C.

The researchers are working to enhance the heat resistance of the developed materials by optimizing the composition, for example by adding functional elements such as zirconium. In addition to enhancing emission-control systems of automobiles, Asao says the nano-rods could also find applications in catalysis, fuel cells, ultraviolet blockers, solar cells and sensors. ■

Business News

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Plant Watch

ICA Fluor to build $1-billion petroleum-refining facility in Mexico

January 11, 2016 — ICA Fluor, Fluor Corp.'s (Irving, Tex.; www.fluor.com) joint venture (JV) with Empresas ICA, S.A.B. de C.V. (www.ica.com.mx/ir), was authorized by Pemex to proceed with the engineering, procurement and construction (EPC) of the Madero Clean Diesel project at the Madero Refinery in Tamaulipas, Mexico. The project, scheduled for completion in 2018, includes two 25,000-bbl/d diesel hydrodesulfurization trains and associated facilities, as well as new hydrogen, sulfur-recovery and sour-water-treatment plants.

Technip awarded contract by Air Products for Baytown hydrogen plant

January 8, 2016 — Technip (Paris, France; www.technip.com) was awarded a contract by Air Products (Lehigh Valley, Pa.; www.airproducts.com) to provide technology, engineering and procurement services for a grassroots hydrogen plant in Baytown, Tex. The plant will produce 3.5 million m^3/d of hydrogen and carbon monoxide. The project is scheduled to come online in 2018.

PPG to increase precipitated silica production capacity at Lake Charles plant

January 7, 2016 — PPG Industries, Inc. (Pittsburgh, Pa.; www.ppg.com) is increasing precipitated silica production capacity at its Lake Charles, La., manufacturing plant by more than 10,000 metric tons per year (m.t./yr). PPG plans to achieve the capacity increase through debottlenecking projects that are expected to come online in the second half of 2016.

Lanxess starts up expanded plastics-compounding line in North Carolina

January 7, 2016 — Lanxess AG (Cologne, Germany; www.lanxess.com) has started up a second production line for high-performance plastics compounding at its facility in Gastonia, N.C. The new line represents an investment of about $15 million and doubles the site's production capacity from 20,000 to 40,000 m.t./yr. In the plant, the basic polymers polyamide and polybutylene terephthalate are mixed and refined with special additives and glass fiber.

CB&I awarded contract for polypropylene unit in Heibei, China

January 6, 2016 — CB&I (The Woodlands, Tex.; www.cbi.com) was awarded a contract by Hebei Haiwei Group for a polypropylene unit to be built in Jingxian, Hebei Province, China. The unit will use CB&I's Novolen technology to produce 200,000 m.t./yr of polypropylene.

Air Liquide enters Colombian industrial-gas market with construction of new plant

January 6, 2016 — Air Liquide (Paris, France; www.airliquide.com) will build and operate a new facility consisting of a carbon dioxide production unit and a cogeneration unit. In addition, the site will supply nitrogen, electricity, refrigerated water, compressed air and steam. With an investment of around €40 million, the Tocancipá-based facility is expected to start up in late 2016.

Showa Denko expands production of high-purity ammonia in Taiwan

December 28, 2015 — Showa Denko K.K. (SDK; Tokyo, Japan; www.sdk.co.jp) has expanded its capacity to supply high-purity ammonia, which is widely used in production processes for electronic materials, by stepping up the production capacity of a plant owned by its manufacturing subsidiary in Taiwan from 2,500 to 3,500 m.t./yr.

Dow announces startup of commercial operations for PDH unit in Texas

December 21, 2015 — The Dow Chemical Co. (Midland, Mich.; www.dow.com) announced that its new propane dehydrogenation (PDH) unit located at the company's Oyster Creek site in Freeport, Tex., has begun commercial operations. Capacity for the new propylene production facility is 750,000 m.t./yr, making it the largest on-demand propylene facility of its kind, according to Dow.

Shell-CNOOC JV to expand ethylene and derivative units at Nanhai complex

December 16, 2015 — Shell Chemical LP (Houston; www.shell.com/chemical) announced that Shell Nanhai B.V. and China National Offshore Oil Corp. (CNOOC) have signed an agreement to expand their existing 50-50 JV in Huizhou, China. The expansion includes the construction of an ethylene cracker and ethylene derivatives units, including a styrene monomer and propylene oxide plant. The new cracker will increase Nanhai's ethylene production capacity by over 1 million m.t./yr, about double its current capacity.

Mergers & Acquisitions

Solvay's phosphorus-based water additives business acquired by Italmatch

January 12, 2016 — Solvay SA (Brussels, Belgium; www.solvay.com) has entered into an agreement under which its business unit consisting of desalination and water additives based on phosphonates and phosphonic acid will be acquired by Italmatch Chemicals Group. In particular, the agreement covers the acquisition of all products, trademarks, patents and client portfolio from Solvay.


ROSS

BP to sell petrochemicals plant in Alabama to Indorama

January 6, 2016 — BP plc (London; www.bp.com) has agreed to sell its petrochemical complex in Decatur, Ala., to Indorama Ventures Public Co. (Bangkok, Thailand; www.indorama.net). The parties anticipate that the deal will close in early 2016. The facility can produce purified terephthalic acid (PTA), *para*-xylene and naphthalene dicarboxylate.

Albemarle finalizes sale of its metal sulfides business

January 5, 2016 — Albemarle Corp. (Baton Rouge, La.; www.albemarle.com) has completed the sale of its Tribotecc metal sulfides business to Treibacher Industrie AG. The transaction includes sites in Vienna and Arnoldstein, Austria, and Tribotecc's proprietary sulfide synthesis process. Financial terms of the transaction were not disclosed.

Dyadic closes sale of Industrial Technology business to DuPont

January 4, 2016 — Dyadic International, Inc. (Jupiter, Fla.; www.dyadic.com) closed the sale of its Industrial Technology business to DuPont (Wilmington, Del.; www.dupont.com) for $75 million in cash. The acquired business will be integrated into DuPont's Industrial Biosciences division.

Saint-Gobain acquires specialty-tubing company in Brazil

January 4, 2016 — Saint-Gobain (Courbevoie, France ; www.saint-gobain.com) has acquired SG Plasticos, a producer of specialty extruded tubing located in São Paulo, Brazil. SG Plasticos provides differentiated and customized solutions related to fluid transfers in many markets.

Celanese forms JV for cellulose-based specialty products

December 22, 2015 — Celanese Corp. (Irving, Tex.; www.celanese.com) has entered into a memorandum of understanding with China-based Push Group Co. to form a new JV focused on the production of cellulose-acetate-based specialty products, including plastics and films. The execution of the agreement is expected to occur before the end of March 2016.

Huber to purchase two business units from Albemarle

December 17, 2015 — Albemarle Corp. has signed an agreement to sell its Mineral Flame Retardants and Specialty Chemicals businesses to Huber Engineered Materials (Atlanta, Ga.; www.hubermaterials.com). The transaction includes Albemarle's Martinswerk GmbH subsidiary located in Bergheim, Germany and Albemarle's 50% stake in Magnifin Magnesiaprodukte GmbH, a JV with RHI AG at Breitenau, Austria.

Sinopec acquires minority stake in Sibur

December 17, 2015 — Sibur (Moscow; www.sibur.com) and China Petroleum & Chemical Corp. (Sinopec) announced the successful completion of Sinopec's 10% minority investment in Sibur as a strategic investor. The investment will lead to the sharing of joint expertise and resources, and Sinopec will have the right to nominate a representative to Sibur's Board of Directors. ■

Mary Page Bailey

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Painting it 'Green'

Driven by consumer demand and regulatory pressure, paint and coating formulators, along with makers of chemical additives for those markets, have brought to the forefront products with improved environmental and health performance

IN BRIEF

- LOW-VOC PAINT PERFORMANCE
- ZERO-VOC PAINTS
- NEW ADDITIVES
- DIMENSIONS OF SUSTAINABILITY
- ADDING FUNCTIONALITY

Modern paints and coatings are complex mixtures of film-forming substances, fillers, pigments and a host of additives (see box, p. 17). Many of the compounds traditionally used in paint and coating formulations present significant environmental and human health risks. Spurred by tightening regulations and growing demand for healthy and sustainable products on the part of end-users, the paints and coatings industry has delivered a wide range of materials with significantly improved environmental and health properties. And thanks to a continued focus on innovation, many of the newer environmentally friendly paints and coatings have begun to achieve parity with conventional products in performance.

"The drivers behind the development of sustainable paints are really a combination of both regulatory pressure and consumer demand," says Chris Connelly, director of brand management at Benjamin Moore (Montvale, N.J.; www.benjaminmoore.com). "The development started as a way to comply with environmental regulations, but now, consumers, contractors, and facility managers are more aware of the social and environmental impacts of products, and are demanding paints with lower environmental and health impact."

In general, the advancements in paint and coating technology related to environmental impact have come as a result of several factors, including the development of better formulation technology and the availability of new additive options. "The current state of the art is a result of an accumulation of many small innovations that have added up to large advancements in the environmental performance of paints," says Chris Cook, director of the Planet Possible program at AkzoNobel (Amsterdam, the Netherlands; www.akzonobel.com).

"The technology of environmentally friendly paints has expanded significantly over the last 10 years and this technology expansion was enabled by innovation," says Murray Hemsley, global market leader for Architectural & Protective Coatings at Eastman Chemical Co. (Kingsport, Tenn.; www.eastmanchemical.com). "The primary focus across both architectural and industrial coating applications has been on technology that enables maximum performance while still meeting stringent volatile organic compound (VOC) and emission requirements," he remarks.

In addition to paint formulators developing better methods for combining paint components, the companies supplying them are also now looking for ways to deliver more environmentally sustainable chemicals to use in their formulations. AkzoNobel's Cook says his company, along with others, are now pushing harder on suppliers to engage in more sustainable practices.

Low-VOC paint performance

Historically, one of the major environmental challenges associated with paints and coatings has been due to high levels of VOCs and other species that can have negative effects on indoor air quality, contribute to smog formation and adversely affect long-term human health (see box, p. 18).

"Modern paint makers have moved away from the old model of making paints with solvents like ketones, toluene and other organic solvents," explains William Golton, a former industry consultant and former analytical chemist at DuPont. "Now, all the VOCs in most paints come from the additives, and in many cases, the high-VOC additives are now being substituted by higher-boiling compounds that have the same effect on the paint properties," he says.

AkzoNobel's Chris Cook continues, "The development of more sustainable paints is an extension of the long-running trend to 'greener' products, and the movement away from solvent-based products is expanding from wall paints to the trim and wood-care products market, including stains, varnishes, lacquers and polyurethanes. Paints have largely made that switch, already, but other product sectors are doing the same."

Lowering VOC levels in paints has been a central area of innovation for the paint industry, says Golton. "For low-VOC automotive finishes, it remains more difficult to achieve comparable performance to solvent-based products at the same cost than it is for paint at this point," he says. "The challenge there is that it is a bigger technological leap to go from a solvent-borne product to a waterborne product than it is to substitute additives in a product that is already waterborne."

"In the architectural-coatings industry, low-VOC is no longer a specialty product offering; it is a must-have option for all brands in the space," says Mary Ellen Shivetts, senior product stewardship man-

PAINT COMPONENTS

Paint can be considered a liquid mixture that, when applied to a substrate, converts to a solid film. Paints are varied and can be very complex. Most paints are composed of the following four major categories for paint ingredients: binders (the film-forming component); the solvent (to allow the application of the liquid to a surface); pigments (to impart opacity and color); and additives (to modify application and finish properties).

Binders. Paint binders bind the pigment molecules to form a film and bind the film to the substrate. Binders are usually synthetic or natural resins, such as alkyds, acrylics, vinyl-acrylics, vinyl acetate/ethylene, polyurethanes, polyesters epoxies and others. Binders are sometimes categorized by the mechanisms for drying or curing. The binder material often surrounds particles of pigment materials. The drying process involves the evaporation of the solvent, as well as typically an oxidative cross-linking process for the polymers in the binder.

Solvents. The solvents carry the nonvolatile parts of the paint and control the viscosity of the paint during the application process. For waterborne paints, water is the solvent, while solvent-borne paints can have a variety of organic compounds, including aliphatic hydrocarbons, aromatic compounds, ketones, alcohols, esters, ethers and others.

Pigments. Pigments are generally granular solids that are incorporated to give the paint color. Titanium dioxide, pthalo blue and red iron oxide are often used to give paint opacity and color. Engineered molecules and dyes are often used in paints as well

Additives. Usually added in small amounts, paint additives can have a significant impact on paint properties. Common categories for additives include rheology modifiers, surfactants, driers, foam-control agents, anti-settling agents, wetting agents, biocides and others.

VOC HEALTH EFFECTS, LIMITS AND MEASUREMENT

Although definitions for volatile organic compounds (VOCs) can vary depending on the context, the key aspects for paints and coatings involve organic compounds with low boiling points that can undergo chemical reactions in the atmosphere as a result of interaction with ultraviolet radiation. Aliphatic hydrocarbons, acetone, ethyl acetate, glycol ethers and others are VOCs that have been used as ingredients in paint and coating formulations. Health effects of VOCs generally depend on the concentration in the air, and on how long and how often a person breathes the air. Acute effects can be eye, nose and throat irritation, nausea, headaches and exacerbation of asthma symptoms. Chronic exposure to high levels of VOCs can increase the risk of certain types of cancer, liver and kidney damage and the risk of damage to the central nervous system. For more information on health and VOCs, visit the Indoor Air Quality Scientific Findings Resource Bank (iaqscience.lbl.gov).

In the U.S., VOCs in paints are regulated by the Environmental Protection Agency (EPA; Washington, D.C.; www.epa.gov). Federal VOC limits are now set at 250 grams per liter (g/L) for flat paints and 380 g/L for others. The establishment and evolution of VOC limits for paint has seen a large degree of input from industry. “The whole history of VOCs in paint is a good example of how industry can work with government to produce win-win situations,” Golton says. There are now much better-performing paints with much lower VOC content. So the public got less pollution and the paint manufacturers got better paint.

Some states and regions have lowered the VOC levels for paints that can be legally sold in their areas beyond those required by U.S. federal regulations. For example, California’s standards are more stringent: 150 g/L for nonflat finishes and 100 g/L for flat. In areas where smog can be a public health problem, the limits go further. The South Coast Air Quality Management District (SCAQMD; Diamond Bar, Calif.; www.aqmd.gov), the air-pollution control agency for the areas surrounding Los Angeles, has set an even more ambitious limit — 50 g/L of VOC for all finishes. So-called “super-compliant” products meet a standard of less than 10 g/L, explains Sam Atwood of the SCAQMD. He says that over the past 20 years, more than 50 ton/d of VOC emissions have been reduced from architectural coatings through four major rule amendments and a fee/reporting rule adopted in 2008, which has provided incentive to manufacturers to further lower VOC emissions.

Legislation to limit and lower VOC emissions are becoming more common elsewhere also. The European Union has reduced VOC limits in regulations put forth in 2007 and again in 2010. Also, its REACH legislation on chemical toxicity affects VOC use. China is moving to limit VOCs because of air-quality issues resulting in part from rapid development.

Measurement. Measurement of VOCs has historically been an imprecise process. EPA’s Method 24 is said to be unreliable for paints with very low levels of VOCs. At lower VOC levels, the test has had a difficult time achieving accurate measurements. In its new GS-11 standard (see box, p. 20), GreenSeal says it has incorporated a more direct method into the standard that produces a more accurate reading as the amount gets smaller. The test is estimated to be 10 times more effective and improves further as the VOC gets closer to zero

“The old Test Method 24 was set up a long time ago, when a lot of the companies didn't have big laboratories,” says former consultant Golton. “That meant it had to be easy to do, but the rudimentary test was never intended to measure VOC levels below 100 g/L.” A newer test method, ASTM D 6886 is based on gas chromatography, and has gained wide acceptance in the U.S. A similar method is the standard in Europe.

The SCAQMD is aware of those drawbacks and uses Method 313-91, which is supposed to be more accurate for no- and low-VOC paints. Although companies acknowledge the unreliability of Method 24, it remains the only method that can be used for certification. The EPA has not yet revised Method 24 to give manufacturers another option.

ager for PPG Architectural Coatings (Pittsburgh, Pa.; www.ppgac.com) in the U.S. and Canada.

The shift to new materials has required much effort to negotiate the tradeoffs that arise among the various attributes of paints and coatings. “In the past, the perception was that a better environmental profile necessarily meant a sacrifice of performance, but the industry has improved significantly in both environmental and paint performance, a tradeoff between the two may not be necessary,” says AkzoNobel’s Cook.

Eastman’s Murray Hemsley agrees: “Companies understand that consumers are not usually willing to trade off quality for sustainability, and through hard work and formulation expertise, paint formulators are very close to matching the performance of conventional paints [with their low-VOC products].”

AkzoNobel’s Cook says performance improvements for low-VOC paints have been made “across the board, but especially at the higher price points." One issue that remains for low-VOC is glossiness — a high-gloss finish with no brush marks is still hard to achieve with water-based products, Cook notes.

Zero-VOC paints

While the proliferation of low-VOC (designated by VOC levels lower than 250 g/L) coatings products continues, there is a considerable push to achieve much lower levels than that in many market segments. Paint sellers such as Benjamin Moore, Sherwin-Williams and several others have pushed the VOC levels lower, to a point where they can be marketed as “zero-VOC” paints. Truly zero-VOC paints do not exist, says former industry consultant Golton, but the levels in these paints are less than 5 g/L of VOCs in order to be classified as “zero-VOC.”

Benjamin Moore’s zero-VOC product lines Natura and Ultra Spec are among the growing offerings. “In the past you could expect lower levels of durability, or perhaps different application characteristics [for zero-VOC],” says Glenn Cooper, vice president of product development for Benjamin Moore, "but we have really conquered those issues now.”

Health risks also have decreased. The zero-VOC Natura brand, for example, has been certified asthma- and allergy-friendly by the Asthma and Allergy Foundation of America, Cooper notes.

PPG offers the PPG Pittsburgh Paints Wonder-Pure brand, a zero-VOC interior latex paint and related primer with low odor, which allows painters and maintenance professionals to paint in occupied spaces with little disruption, PPG says.

New additives

Although typically accounting for only 0.5–5.0 wt.% of a paint, additives play a critical role in the paint’s properties, including those having to do with environmental and health impact. Research and development investment over the past several years on new additives for paints and coatings is now bearing fruit. Chemical companies are offering new options for paint formulators to reduce environmental impact.

For example, Eastman's MAK (methyl *n*-amyl ketone) and MIAK (methyl isoamyl ketone) solvents help offer routes to reduce VOC emissions in coatings applications. MAK and MIAK are high-boiling specialty ketones with good solvent activity and slow evaporation rates. They allow paints to achieve higher solids and lower emissions while maintaining excellent flow and leveling properties and optimal spray viscosities, Eastman says.

Eastman's Hemsley says there have been innovations in ultra-low VOC and zero-emission coalescents, molecules that help emulsion-based paints form a film as the water evaporates. Also, specialty cross-linking monomers have been introduced to polymer manufacturers, which enable the polymers contained in paint to perform at a higher level while delivering low-VOC-emission formulations.

Eastman's Texanol and Optifilm products allow water-borne polymers to be used in architectural paints rather than requiring an organic solvent-based system. "Optifilm enhancer 400 allows the film-forming mechanism to take place without emissions," Hemsley says. Texanol ester alcohol helps the discrete water-borne polymer particles to coalesce and form a strong durable film, he adds.

For industrial coating applications, Eastman cellulose-ester products, such as the family of Eastman Solus performance additives, allow for rheology control and metallic flake orientation within higher-solids, lower-emission coatings.

Dow Coating Materials (Philadelphia, Pa.; www.dowcoatingmaterials.com) has also introduced several paint-additive products that can help reduce environmental impact and lower VOC content. For the industrial coatings market, Dow has developed technology for improving the performance of waterborne alkyd coatings. Alkyds are polyesters modified by adding fatty acid molecules, and they have been used for industrial coatings because of their excellent finish properties. But low-VOC regulations have reduced their use in many regions, Dow says, and waterborne alkyd emulsions haven't matched the performance of solvent-borne alkyd systems. Dow has developed technology to disperse traditional high-viscosity, short-oil alkyds with minimal surfactant and no polymer modification. These attributes allow for the formulation of pigmented waterborne alkyd coatings with comparable dry times, adhesion and hardness to those of conventional solvent-borne alkyd coatings.

In the architectural coatings market, Dow has also developed binder materials that can be formulated at lower VOC levels, but that maintain the hardness properties of a higher-VOC paint. Typical approaches to

THIRD-PARTY CERTIFICATION

Reflecting the growing consumer demand for products with positive sustainability characteristics, third-party certification organizations focused on sustainability have become a major factor driving the development and use of low-VOC paints and coatings. An example is the not-for-profit organization GreenSeal (Washington, D.C.; www.greenseal.org), which released in December 2015 an updated and expanded standard for architectural coatings. Knowns as GS-11, the revised standard is designed to encourage paint formulators to use chemicals with less risk to human health and the environment. In order to meet the standard, and thus be able to earn GreenSeal's emblem on product labels, the "products must restrict carcinogens, toxins affecting reproduction, hazardous air pollutants, heavy metals, formaldehyde, certain phthalates and other chemicals," GreenSeal says. "The standard also ensures that certified paints, coatings, stains and finishes still deliver the same functional performance that consumers expect from conventional architectural coatings," GreenSeal adds. Green Seal's certification process involves criteria based on scientific research, an in-depth review of product data, manufacturing procedures and claims on product labels, and an on-site audit of facilities. Periodic monitoring is required to maintain certification.

Another example of third-party certification comes from the U.S. Green Building Council (USGBC; Washington, D.C.; www.usgbc.org), the organization responsible for LEED (Leadership in Energy and Environmental Design) certification in new buildings. The LEED rating system offers a credit toward LEED certification for buildings that use low- or zero-VOC paints in construction or renovation projects. The credit covers VOC emissions into indoor air and the VOC content of materials, as well as the testing methods by which indoor VOC emissions are determined.

The USGBC's Brendan Owens says the organization is trying to guide project teams to make better decisions related to sustainability. "In terms of paints, we are looking at primarily two areas: the environmental impact of the manufacturing process, and the environmental and human health impact of the paint when applied." The main criteria for paint are emissions, material sourcing, sourcing disclosures, disclosure of chemicals and optimization of material ingredients to minimize the use of environmentally problematic chemistries where possible, Owens explains.

He notes that 80% of the over 70,000 projects that have applied for LEED certification earn the paint credit. "LEED is a huge driver for the 'built environment' now, and the offerings for low-VOC and environmentally friendly paint products are better than ever before.

develop lower-VOC paint formulations can result in films with a tacky feel. Dow investigated post-film-formation polymer crosslinking chemistries and worked on optimizing particle morphology for latex particles. The company's optimized binders, including its RHOPLEX 800h Binder, showed a significant improvement in hardness profile.

In Oct. 2015, Dow introduced ROVACE 10 Emulsion, a low-VOC emulsion with high (55%) solids content. The product was designed for easy processability and requires little or no coalescing solvents, allowing lower VOC content, the company says.

In Europe, Perstorp AB (Stockholm, Sweden; www.perstorp.com) has expanded production of its polycaprolactone polyols products, which can be used as a building block to make waterborne polyurethanes with low VOC profile, David James, VP of innovation surface technology, Perstorp, explains. Polycaprolactone polyols are a type of polyester made with a ring-opening polymerization process, rather than a condensation polymerization reaction. Perstorp's polycaprolactone products, known as Capa, have low viscosity, so they can act as solvents in paint, lowering the need for VOC-containing components, James says.

Lanxess AG (Cologne, Germany; www.lanxess.com) has taken aim at improving the environmental impact of processes to make inorganic paint pigments. Specifically, the company will start production of red pigments using a new, more sustainable process. For more, see p. 9 (this issue).

Dimensions of sustainability

Although a key issue, VOC content in paint is not the only concern for environmental impact. In addition to VOC levels, durability, recyclability, functionality and other factors can have an impact on paint "greenness" and sustainability profile. AkzoNobel's Cook remarks that making paints more environmentally friendly can involve lowering paint's carbon footprint by using lower-carbon formulations and improving the logistics for upstream raw materials.

In addition, advances in durability can make a difference — longer lifetimes for paint mean that even a product with a higher environmental impact initially could be better overall if the paint lasts longer than the other products and does not have to be applied as often.

"As the low- and zero-VOC paint space progresses, we find that consumers will be looking at additional ways to be environmentally friendly, such as using recycled paints or paints made from bio-renewable resources, or participating in post-consumer paint recycling programs," says PPG's Shivetts

Adding functionality

Another focus for developing better environmental performance in paints and coatings is part of a wider trend to add specific functionality to paints and coatings.

For example, AkzoNobel has developed exterior paint technology that helps buildings stay cooler in warm weather, and thus lower the energy costs associated with cooling them. AkzoNobel's KeepCool and SunReflect brands are designed for use in tropical climates, and have been used in Asia since 2014. By carefully selecting pigment molecules that do not absorb infrared (IR) radiation, the exterior paint can reflect more IR and prevent it from heating up the building walls. External testing has shown that the new AkzoNobel paints can reflect up to 90% more IR radiation than comparable exterior paints. This could translate into energy savings of 10% on a 15-story building, or higher in a small bungalow, AkzoNobel says. Another example of an environmentally relevant additive is the company's Dulux Guardian coating products, which can absorb air pollutant species by incorporating charcoal additives into the paint.

Many of PPG's zero-VOC products, including its PPG Paint Pure Performance brand, incorporate a mold- and mildew-resistant compound that makes the dry paint film resistant to a range of mold species. ■

Scott Jenkins

Sealing Solutions to the Rescue

Improved seals, gaskets and valve packings stand up to tougher process conditions

Chemical processors expect more from their seals, gaskets and valve packings than ever before, as sealing components must meet tighter and stricter regulations regarding emissions, stand up to tougher process conditions and perform for greater lengths of time in the extreme sealing environments of the chemical process industries (CPI). Failure of sealing elements is not tolerated because the impact can be costly and catastrophic.

A.W. Chesterton

FIGURE 1. Certified Low-E valve packings, like Chesterton 1622 valve packing, can help reduce fugitive emissions from valves. This high-performance, graphite valve-stem packing blocks valve fugitive emissions to below consent-decree requirements

Sealing challenges

According to industry experts, there are several significant challenges facing chemical processors and their sealing applications. The first major concern is an ever-decreasing allowable limit on emissions. While methane is a hot-button issue for the petroleum refining industry at the moment, there is a general emphasis on the reduction of hydrocarbons, volatile organic compounds (VOCs) and greenhouse gas (GHG) emissions throughout the CPI.

"Right now there is a major focus on the proposed reduction of methane emissions in the oil-and-gas sector, but there is a general emphasis from the [U.S.] Environmental Protection Agency (EPA; Washington, D.C.; www.epa.gov) on VOC emissions, as well," notes Henri Azibert, technical director with the Fluid Sealing Association (FSA; Wayne, Pa.; www.fluidsealing.com). "Because VOCs are found throughout the CPI, processors need to look at the components that are leaking — meaning their seals, packings and gaskets — and find better alternatives if they are not meeting the current or expected regulatory requirements."

In addition to a drastic reduction in permissible emission limits over the last few years, chemical processors are also faced with the prospect of dealing with process changes aimed at boosting their production in an effort to remain competitive in a global economy. For many, this means increasing process temperatures, which creates extremely harsh process environments. "Everyone wants to increase their efficiency, which is often accomplished by increasing their process temperatures," explains Andreas Schmiedel, technical manager of life science and process industries for Europe with Trelleborg Sealing Solutions (Fort Wayne, Ind.; www.tss.trelleborg.com). "Not only are the higher process temperatures a challenge for sealing components, but when you increase the temperature, the media that is running through the process often becomes more aggressive, as well, which can also be very challenging and damaging to the seals and gaskets used in process."

Along with the stressors of lower emissions and more difficult process conditions, there is also a need for longer intervals between seal maintenance, as workforces continue to shrink, uptime demands increase and costs must continually be reduced, meaning that the lifetime of seals, gaskets and valve pack-

IN BRIEF

SEALING CHALLENGES

ADVANCED TECHNOLOGIES

REDUCING EMISSIONS

DESIGNING FOR HARSH PROCESSES

Evonik Industries

FIGURE 2. Evonik's Vestakeep 5000, a ductile polyetheretherketone (PEEK), is available as a granule for injection molding and extrusion to fulfill the design challenges for seals and gaskets. A recent development on that initial material, Vestakeep 5000 HCM, can also be adapted to improve the sliding and wear resistance needed in some applications

ings must be extended. "This makes for a tricky situation because we are expected to provide materials that do a better job in a more difficult environment, but last longer than ever before," notes Schmiedel.

Advanced technologies

"While seals, such as bolted joint seals and valve-stem seals in a process plant, may not appear to be that significant and, as a result, may be neglected, any maintenance or plant manager can tell you that when a seal leaks, it can bring the whole plant down, result in drastic fines or create dangerous working conditions," says Raman Hanjra, global product line manager, stationary equipment sealing, with A.W. Chesterton Co. (Groveland, Mass.; www.chesterton.com). "This is where sealing solution manufacturers, working with end users, can devise sealing solutions that do their job and do it well so that end users can continue to focus on their core business without worrying about seal failure."

Matt Tones, applications engineer with Garlock Sealing Technologies (Palmyra, N.Y.; www.garlock.com), agrees: "We recognize that there are a lot of sealing challenges in today's process environment, so we have to develop products that meet the regulatory, process and reliability requirements. Essentially, it's our goal to build a better mousetrap. We are familiar with and know how to effectively recommend the right materials and designs for these applications, so the next

Trelleborg Sealing Technologies

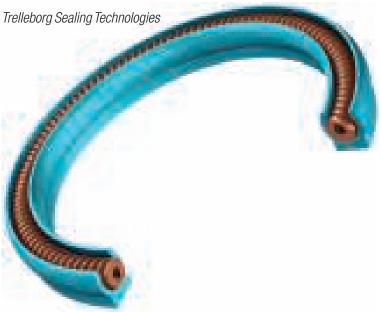


FIGURE 3. A PTFE-based sealing product, Turcon Variseal Ultra-Clean from Trelleborg, was developed to stand up to the harsh environments created by CIP, SIP and other high-temperature, aggressive sanitary environments

step is to take those materials and designs, innovate and improve the existing properties, which are already very good, and make them even better."

And, for each challenge, there is often an innovative solution available.

Garlock Sealing Technologies

FIGURE 4. Garlock's THERMa-PUR is a proprietary new gasketing material designed for use in high-temperature sealing applications. It provides sealing at temperatures up to 1,832°F, where gaskets of other materials, such as graphite, cannot survive

Reducing emissions

It's no secret that EPA continues to tighten regulations regarding allowable limits on emissions of all types of pollutants. As part of the regulatory requirement, processors must have programs in place to measure and monitor emission levels at potential points of emission, such as valves and flanges, and if they find a component leak above a certain level, they are required to fix it. "This can be a costly method that requires a lot of labor, but it's very effective," notes FSA's Azibert.

One of the ways to reduce the emission level at any given point, and, in turn, reduce the amount of effort to remain in compliance, is to employ specialized low-emission (Low-E) sealing solutions in problem areas, says Ron Frisard, field product manager, stationary equipment, with A.W. Chesterton.

He says that using certified Low-E valve packings, like Chesterton 1622 valve packing (Figure 1), can help reduce fugitive emissions from valves. This high-performance, graphite valve-stem packing blocks valve fugitive emissions to below consent decree requirements. A non-hardening, flexible packing, constructed from Inconel-reinforced mesh with internal exfoliated graphite, it will not shrink or absorb moisture. The single-spool solution reduces inventories and installation errors caused by using multiple types of rings in various orientations. It is suitable for use in a variety of applications to seal light and heavy hydrocarbons, VOCs and most non-oxidizing chemicals in the hydrocarbon processing and chemical industries.

Designing for harsh processes

"One of the biggest concerns about sealing components in the chemical industry is their ability to stand up to corrosion and to resist chemicals," notes Azibert. "There are different materials for these applications and manufacturers continue to develop fillers and new formulations on the existing products to keep up with the demands of the process industry."

Uwe Kannengiesser, global technical coordinator and key account manager for Vestakeep, with Evonik Industries AG (Essen, Germany; www.evonik.com), agrees. "There is an increasing demand for a material that can operate in a high-heat environment, but also provide excellent resistance against corrosive and chemical media. In addition, the material has to offer higher service lifetime for a significantly longer interval between maintenance," he says.

For example, he says that for back valve rings and compressor plates there is a need for ductile material with higher fatigue resistance. "This is because brittle material has been found to fail in shorter operation times as it has a poor resistance against dynamic stresses," he says. "Another criteria gaining importance is the wear resistance of the material. A low sliding coefficient translates into low energy consumption."

To meet this myriad of requirements, Evonik has developed Vestakeep 5000 (Figure 2), which is a ductile polyetheretherketone (PEEK) available as a granule for injection molding and extrusion to fulfill the design challenges for seals and gaskets. A recent development on that initial material, Vestakeep 5000 HCM, can also be adapted to improve the sliding and wear resistance needed in some applications.

Polytetrafluoroethylene (PTFE) is another material commonly used to meet the demands of the CPI, including chemical resistance, and sealing product manufacturers are constantly developing new formulations, blends and configurations to stand up to challenging conditions, such as higher temperatures, hazardous chemicals and other harsh conditions. For example, Garlock's Gylon Stress Saver Style 3504 combines the Gylon Style 3504 PTFE gasketing with aluminosilicate microspheres, which provides a tighter seal over conventional PTFE. The Stress Saver family of products is designed with molded, raised ribs to help create a tighter seal by concentrating the compressive load. Combining the two technologies provides many benefits over conventional rubber or elastomeric gaskets, including chemical resistance, superior physical properties, such as greater temperature and pressure capabilities, and limited creep and cold flow to reduce leakage.

Another PTFE-based product, Turcon Variseal Ultra-Clean from Trelleborg (Figure 3), was developed to stand up to the harsh environments created by clean in place (CIP), sterilize in place (SIP) and other high-temperature, aggressive sanitary environments, says Schmiedel. In the design of this product, the spring required to activate the seal is fully enclosed within a Turcon PTFE-based case. In food, beverage and pharmaceutical applications, this ensures there is no dead space for bacteria to be caught. The seals combine wear resistance and compatibility to virtually all chemicals, even in extreme operating temperatures, which provides long life in CIP and SIP regimes.

Trelleborg has also been working with new materials for mechanical seals. Isolast J9876 was developed using a new perfluorelastomer (FFKM). The new compound removes the need for multiple grades supporting different applications and it holds the necessary approvals for use in food contact and pharmaceutical applications, such as FDA, 3A-Sanitary and USP Chapter 88 Class VI. It provides long-term physical property retention due to its compatibility with virtually all media, its suitability to high-temperature applications and its potential for application in steam and water, says Schmiedel.

Similarly, Garlock's THERMa-PUR (Figure 4) is a proprietary new gasketing material designed for use in high-temperature sealing applications, as it provides sealing at temperatures up to 1,832°F, according to Tones, where gaskets of other materials, such as graphite, cannot survive. "This product excels in applications where processors are discovering improved process yield via increased temperatures," Tones says.

"The products we are developing today not only provide protection from leaks and stand up to harsh chemical processes, but in doing so, they also provide the reliability our processing customers demand," Tones notes.

"Reliability of seals in harsh conditions is important for so many reasons," continues A.W. Chesterton's Hanjra. "Reliability can help mitigate the risk of an emissions leak and/or a plant shutdown, which, in turn, helps decrease the overall cost of ownership of the equipment. The expense of upgrading your sealing solutions is quite small when you consider that it reduces the risk of emissions leaks or issues that can create a safety or production issue, which can be very costly. Better sealing technologies are always a worthwhile investment because they can lead to higher uptime and production rates." ■

Joy LePree

Software and Mobile Apps

Advance engineering projects with process simulation tools

ChemCad is an intuitive suite of chemical-process-simulation software that gives engineers a variety of capabilities to improve productivity. Version 6.5.7 includes such features as the Thermo Acceleration operating mode, which can help speed calculations for complex simulations. The software also allows for simultaneous heat-transfer and mass-transfer models in distillation columns, and lets users run Excel Data Maps for each time step in dynamics mode. *— Chemstations, Inc., Houston*
www.chemstations.com

Platform eases collaboration, data sharing and compliance

The ability to improve the aggregation, integration, synthesis and analysis of data from disparate resarch and operating areas within an organizations lets process engineers and managers uncover knowledge that is often hidden in massive volumes of structured and unstructured data. BIOVIA Pipeline Pilot (photo) is a graphical-authoring application that increases operational efficiency and reduces costs for both scientists and process engineers across a wide spectrum of industries. With Pipeline Pilot, users can complete projects significantly faster, by leveraging existing research, process and intellectual property, and automating routine data gathering and analysis. Real-time reporting dashboards bring into view experimental results and process production metrics related to a wide range of data-processing functions, such as data retrieval, manipulation, computational analysis, filtering, and display functionalities. *— Dassault Systèmes Biovia (formerly Accelrys), San Diego, Calif.*
www.accelrys.com

Dassault Systèmes Biovia

Program speeds the execution of brownfield projects

Aveva Everything3D 2.1 (Aveva E3D; photo) builds on the software's proven ability to deliver time and cost savings for brownfield and revamp projects, helping to increase productivity for engineering, procurement and construction (EPCs) and owner-operators. Enhanced capabilities, such as PointCloud demolition and the ability to dislay laser data directly on drawings, enable designers to interact with 3-D models in ways that have not previously been possible, says the company. The software's enhanced user interface helps to reduce the learning curve and move projects more quickly into production. Aveva E3D includes the introduction of HyperBubble technology, which is said to allow the user to work in a fully immersed, as-built environment. For many projects, the software's capabilities can reduce the need to remodel existing plants prior to revamps, and limit the need to generate numerous drawings (which cuts labor requirements). *— Aveva Solutions Ltd., Cambridge, U.K.*
www.aveva.com

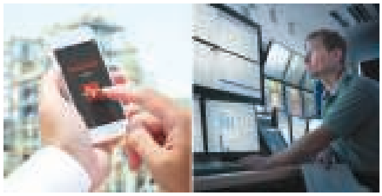
Aveva Solutions

Software bundle supports multivariate data analysis

Two software providers have collaborated to release a software bundle called The Unscrambler X Design-Expert Upgrade, which provides support for multivariate data analysis and design of experiments. It enables advanced multivariate methods, provides a variety of data-visualization tools, and helps users to cut through large data sets that are common in so many chemical process industries (CPI) applications. The software also helps users to screen for vital factors, identify ideal process settings for top performance, and discover optimal product formulations. *— Camo Software, Oslo, Norway, and Stat-Ease, Inc., Minneapolis, Minn.*
www.camo.com

Alarm-management program reduces alarms by 80%

The DynAMo Alarm and Operations Management software (photo) helps CPI operators to better manage operations and alarms, improve operator effectiveness, plant safety, availability and compliance. The solution



Honeywell

Note: For more information, circle the 3-digit number on p. 62, or use the website designation.

provides a single, unified platform and user experience for all operations. It is a scalable offering that allows customers to start with simple Alarm Management or Operator Logbook functionality, and add other functions over time, as needed, to enable a fully integrated Operations Integrity solution. In addition to reducing alarms by up to 80% and reducing root-cause analysis time by 60% over competing methods, the software suite can also increase throughput by up to 8% and cut energy consumtpion by up to 5%, with a typical return on investment of less than three months, says the company. DynAMo can work with any vendor's control system in addition to Honeywell's Experion distributed control system (DCS) platform. — *Honeywell, Houston*
www.honeywell.com

Software upgrade benefits electric inverters and drives

Version 6.60 of the high-speed Perception software (photo) provides

HBM

new capabilities that make it easier to perform high-speed data acquisition on electric inverters and drive systems. It can quickly process large amounts of data — for instance, 100 GB within 10 s — when performing live torque and rotational-speed measurements and calculations, says the company. The software's new eDrive application allows users to visualize torque and rotational speed as live curves. Version 6.60 allows users to create individual "workbenches" that can be defined with distinct restrictions, test functions and capabilities. Password-protection capabilities safeguard key settings, protocols and formulas used in calculations from unwanted access, and intentional or unintentional changes. — *HBM, Marlborough, Mass.*
www.hbm.com

Software provides validation and compliance capabilities

Horiba Scientific

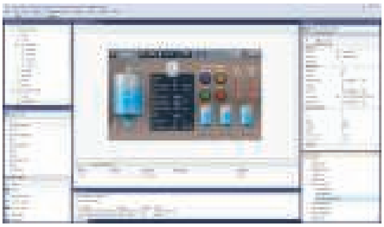
The ProtectionPlus module (photo) provides add-on capabilities to the company's LabSpec 6 Raman Spectrocopy Suite, allowing researchers to handle advanced analytical-laboratory functionalities in a multi-user environment. Protection-

Plus is a fully integrated module that seamlessly adds a layer of security and data integrity, allowing system security administrators to put in place and enforce a wide range of security user and file policies. Specifically, ProtectionPlus allows operators of the company's Raman instruments to work in compliance with Part 11 of the FDA's CFR Title 21, with regard to electronic records and electronic signatures, according to the manufacturer. Additional functionality provided by this optional module includes user account management and access control, a full audit trail to track all data-related operations, an external event log of software functions, and electronic signatures. — *Horiba Scientific, Edison, N.J.*
www.horiba.com

Improve cybersecurity and operator effectiveness

Operating independently from automation vendor platforms allows this company to provide seamless, integrated platform-independent cybersecurity, alarm management and high-performance human-machine interfaces. The ICS Cybersecurity solution strengthens security for critical industrial-control systems. Companies can monitor for unauthorized changes (malicious attacks or inadvertent engineering changes) and drive risk-appropriate remediating actions. The Cybersecurity solution helps operators to automate the processes used for inventory management, security-patch management, change management, and backup and recovery. The PAS Operations Management solution improves situation awareness by helping operators to identify, evaluate and manage alarms and abnormal conditions effectively. The software aggregates, organizes and provides in-context visualization of information from disparate sources within the enterprise, providing invaluable insight into critical operational and safety information.— *PAS, Houston*
www.pas.com

Simplify the design process without multiple tools



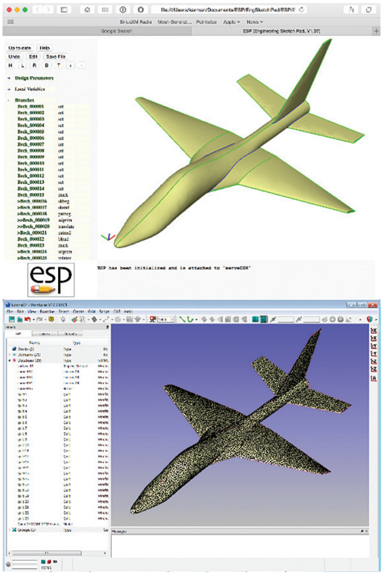
Rockwell Automation

This company has added three new applications to its Rockwell Software Studio 5000 development environment. This platform helps engineers speed the development of automation systems as they design a connected enterprise. These applications, along with the Studio 5000 Logix Designer application, help to improve automation design productivity. The ability to integrate multiple types of functionality into one platform simplifies the design process and reduces the need for multiple tools, says the company. The Studio 5000 Architect application is

the central point, where users can view the overall automation system, configure devices such as controllers and human-machine interfaces (to improve programming efficiency and runtime performance), and manage communication with these devices. Its security features include a variety of user-authentication and access-control options, and a new privilege-escalation capability. Such features improve productivity and system uptime by granting users the right level of access at the right time, says the company. Localized batch control allows controller-based batch sequencing and eventing to simplify system architecture for single-unit control and process skids. — *Rockwell Automation, Milwaukee, Wisc.*
www.rockwell.com

Improve CFD with advanced mesh-generation software

Pointwise



Pointwise Version 17.3 R4 is the latest release of the company's high-fidelity meshing software (photo), which features new native interfaces to numerous computational fluid dynamics (CFD) codes and packages. The Pointwise package generates structured, unstructured and hybrid meshes — a key preprocessing step in the successful use of CFD modeling. It interfaces seamlessly with a variety of CFD solvers from commercial vendors, as well as neutral formats, says the company. — *Pointwise, Fort Worth, Tex.*
www.pointwise.com

Get more from your paperless workflows

Bluebeam Revu combines powerful PDF editing, markup and collaboration technology. With reliable file creation, the program gives users expanded capabilities related to project communications. Three editions of Bluebeam Revu are available: Standard, CAD and eXtreme. For instance, users can mark up PDFs with the program's customizable markup tools, adding, among other things text, notes, clouds, CAD symbols, stamps and highlights. Such custom markups can be saved in the Tool Chest function, allowing easy reuse. Users can also embed photos and videos into markups for added clarity, track annotations in the integrated Markups list, which

can be filtered, organized, customized and exported to Excel. — *Bluebeam Software, Pasadena, Calif.*
www.bluebeam.com

Exploit an industrial-strength cloud to bring results

This company has entered the cloud-services market with Predix Cloud, which is designed specifically for industrial data and analytics. This platform-as-a-service (PaaS) will capture and analyze the volume, velocity and variety of machine data within a highly secure, industrial-strength cloud environment. Cloud computing is expected to enable new levels of industrial innovation. For instance, a highly protected cloud built exclusively to capture and analyze machine data will help to reduce the incidence of countless unforeseen problems and missed opportunities, says the company. Unlike public cloud services, which are open to any individual or organization, Predix Cloud is based on a "gated community" model to ensure that tenants of the cloud belong to the same industrial ecosystem, adds the company.— *GE, Fairfield, Conn.*
www.ge.com

Wireless system and software supports condition monitoring

Manual methods of tracking equipment health to predict faiures is an error-prone and time-consuming approach and can yield incomplete data and understanding of the existing asset conditions. Fluke Connect Assets is a cloud-based, wireless system of software and more than 30 wireless testing tools. The system gives maintenance managers a comprehensive view of all critical equipment, tracking baseline, historical and current test-tool measurement data, current status and past inspection data, enabling users to set up and sustain a preventive maintenance or condition-based maintenance system with minimal investment. The use of wireless test tools eliminates manual recording of measurements, improving the accuracy and validity of the data. The system's features allow maintenance managers to analyze multiple types of predictive data (for example, electrical, vibration and infrared images) to provide a comprehensive assessment of the situation. This allows personnel to see correlations and trends and identify emerging issues. — *Fluke, Everett, Wash.*
www.flukeconnect.com

Software helps users turn data into professional graphs

Origin and OriginPro 2016 are the latest versions of this company's data-analysis and graphing software. The software provides a variety of expanded capabilities, including Smart Plotting with Cloneable Templates to quickly create multi-layer graphs with complex mapping of data plots to worksheet columns. It provides tab-based dialogs for common analysis tools, and supports professional report generation, as well. — *OriginLab, Northhampton, Mass.*
www.originlab/2016.com ■

Suzanne Shelley

New Products

Parker Hannifin

Badger Meter

IDEC

This device reduces costs for compressed air

This company's Air Saver Unit (photo), previously released in Europe and Asia, is now available in North America. The Air Saver Unit is suitable for use in both new and existing factory-floor air-nozzle and air-gun applications that allow uncontrolled blow-offs. The device generates a rapid pulse of air rather than a continuous flow, which, according to the manufacturer, reduces compressed-air costs by as much as 40–50% over typical constant-flow applications. Unlike a continuous stream of air, the pulsed-air blow strikes the work repeatedly, improving the efficiency of the air blow for drying and removing debris. The Air Saver can be easily installed into existing pneumatic systems with no additional programming required for the process logic controller (PLC). — *Parker Hannifin Corp., Cleveland, Ohio*

www.parker.com

These flowmeters benefit from ceramic bearings

The Blancett B1500 Series turbine flowmeter (photo) is designed to perform in harsh environments, providing flow measurements for standard clean, filtered liquid-flow applications in precision industrial processes, such as batching, blending and filling. According to the manufacturer, B1500 Series flowmeters feature exceptional mechanical linearity, which increases the usable flow range and helps mitigate output variance caused by viscosity fluctuations due to changes in fluid temperature. Using a helical rotor design with high-performance ceramic ball bearings, B1500 meters are able to achieve high speed-of-response and minimal pressure drop. Ceramic bearings are also lighter, more tolerant to extreme temperatures and produce less friction than stainless-steel ball bearings, which are commonly found in other turbine meters. B1500 Series meters are available in nominal line sizes from ¼ to 2 in., with an accuracy rating of ±0.25% of reading. Ideal flow ranges vary between 0.25 and 250 gal/min, depending on line size. — *Badger Meter, Inc., Milwaukee, Wis.*

www.badgermeter.com

Track changes and mitigate risk in large capital projects

Project Data Link is a project engineering environment that helps reduce complexity and accommodate changes in capital projects. Project Data Link translates project information, including tag databases and instrument indices, from multiple sources into project deliverables. It mitigates project risk by normalizing specifications into a single data source with traceability and an integrated change-management system. Project Data Link gives suppliers, engineering firms and other stakeholders access to project information, including specifications related to field devices and the distributed control system (DCS). In addition, data provided in various formats are normalized so that all information is available in a single, consolidated standard view. When a change is initiated, Project Data Link automatically reconciles it against what is in the system, identifies what needs to be changed, automatically sends updates to the DCS and provides an audit of what has changed. — *Emerson Process Management, Austin, Tex.*

www.emersonprocess.com

A new HMI with full remote-monitoring capabilities

The Enhanced HG2G-5T Series 5.7-in. human-machine interface (HMI; photo) is available in a color version and a monochrome version, both with high resolution and increased brightness, allowing the screens to be easily read, even in direct sunlight. The Enhanced HG2G-5T HMI can communicate with a variety of different controllers, and supports up to three different communication protocols simultaneously. With operating temperatures ranging from –20 to 60ºC, the HMI is rated for installation outdoors or indoors in washdown areas. A built-in Web server allows full remote monitoring and control via any Web browser running on a PC, smartphone or tablet. Remote users can monitor current values or processes, control operation, change program values and perform troubleshooting and maintenance. — *IDEC Corp., Sunnyvale, Calif.*

www.us.idec.com

Fractional distillation systems for continuous and batch processes

Pope Scientific

This company's stainless-steel fractional distillation systems (photo) are available for batch or continuous processes, and are designed for critical applications, including high-purity processing, fragrances, foods, specialty chemicals, pharmaceutical intermediates, bio-based materials, solvents and so on. Column diameters from 1 to 24 in., and flowrates ranging from less than 1 to greater than 1,000 kg/h cover laboratory, pilot and commercial-production scales. Various types of designs, packings, column internals, control systems and alternate materials, such as Hastelloy and glass, are available. Individual key components or partial systems are also available for users that choose to build their own systems. — *Pope Scientific, Inc., Saukville, Wis.*

www.popeinc.com

Neutralize static in film and sheet production

Vortec

This company's Ionizing Air Knives (photo) neutralize static that can attract dust and contaminants, and stop static discharges that can damage electronic equipment and shock personnel. With this technology, a static neutralizing bar generates positively and negatively charged ions, which are carried to the target by a uniform sheet of amplified air. The air amplifiers use a small amount of filtered, compressed air to deliver a powerful, high-velocity sheet of laminar air over wide areas. This design produces increased thrust and velocity, reduced noise and uniformity, making Ionizing Air Knives suitable for moving webs, films, sheets, strips and other assemblies and objects. Airflow can be adjusted per specific application requirements. Ionizing Air Knives are available in 6-, 12-, 18- and 24-in. lengths. A single ¼-in. NPT compressed-air inlet will feed up to a 12-in. length, and two inlets will accommodate longer models. — *Vortec, Cincinnati, Ohio*

www.vortec.com

Shackelford Services

Supercritical Fluid Technologies

Pepperl+Fuchs North America

This dosing system reduces exposure to materials

The Sure Dose portable dosing system (photo) allows for safer dosing of materials from smaller feed tanks to larger batch or mix tanks. Since the system requires no lifting or suspension of the drum, operator exposure to the materials being transferred is reduced. Utilizing differential-pressure technology, the closed system allows dosing of most liquids, such as biocides, acids and caustics. Since the Sure Dose unit does not utilize delicate load cells, it does not require the supply drum to be elevated, and it can be placed on the floor while dispensing the material. Operators can dispense liquids using various units of measure, such as level, volume or mass, via the user-friendly interface. To ensure compatibility, the dosing system is available with different materials of construction. Available options include an automated control system, along with LED indicator lights for unit status, sensor extension cables and data-logging capabilities. — *Shackelford Services LLC, Olive Branch, Miss.*
www.shackservices.com/home

Android devices for use in hazardous locations

In addition to the Agile X Windows-based 10.1-in. tablet PC system, this company now offers two smaller Android devices that are certified for hazardous areas. The Lumen X4 is a 4.3-in. industrial mobile computer, and the Lumen X7 is a 7-in. industrial tablet for use in harsh environments. The devices survive being dropped or immersed in water, and are resistant to extreme temperatures. The devices also have near-field communication (NFC), Bluetooth 3.0 and two powerful cameras. The Lumen X4 can be optionally equipped with a scanner for recording barcodes. — *Bartec GmbH, Bad Mergentheim, Germany*
www.bartec.de

Modular drying systems for extremely dry process air

This company's Dry-Tec product line contains modular systems for use with extremely dry process air, enabling processes to achieve dewpoint temperatures as low as –65ºC, at volumetric flowrates from 500 to 7,500 m^3/h. The Dry-Tec product line contains a basic sorption module that is used for adsorption and desorption within the system, as well as the precooler module Cool-Tec V and the aftercooler module Cool-Tec N. The precooler and aftercooler modules can optionally be equipped with various filtration elements. In addition to achieving low relative humidity, a nearly particle-free process airflow at the entry and exit of the module system can be provided. Due to their compact design and the modular assembly of the overall system, the units can be easily transported and introduced into existing production facilities. All modular Dry-Tec systems are available with stainless-steel housing. — *ULT AG, Löbau, Germany*
www.ult.de

Determine solubility in a variety of materials with this tool

The Phase Monitor II (photo) determines the solubility of various compounds and mixtures in supercritical and high-pressure fluids. It provides direct, visual observation of materials under conditions precisely controlled by the researcher. Experiments may be performed in liquids, supercritical CO_2 or other liquefied gases. The effect of co-solvents on the solubility of compounds of interest may be investigated as well. The Phase Monitor II allows the user direct observation of the dissolution, precipitation and crystallization of compounds over a wide range of pressures and temperatures. Advanced studies may be done to determine melting-point depressions and the degree of polymer swelling in CO_2 or traditional solvents. Experiments can be performed at pressures up to 10,000 psi and from ambient temperature to 150ºC. — *Supercritical Fluid Technologies, Inc., Newark, Del.*
www.supercriticalfluids.com

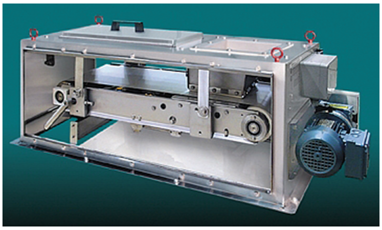
Precisely position movable tools with this encoder

The CVM42H CANopen multi-turn absolute encoder (photo) features stainless-steel housing, flange and shaft, and utilizes magnetic sampling to deliver 24-bit resolution position values. These compact rotary encoders excel in harsh environments with high mechanical stresses, and can

withstand constant shocks and vibrations, high bearing loads, dirt and temperature fluctuations. They are typically found in mobile equipment, steel production, wind turbine and packaging applications. CVM42H absolute encoders are available with various environmental ratings and are rated for use in operating temperatures from –40 to 85°C. They are vibration resistant to 30 g, and shock resistant to 300 g, and their resolution of up to 1 deg offers very precise positioning of movable tools. — *Pepperl+Fuchs North America, Twinsburg, Ohio*
www.pepperl-fuchs.us

Weigh and meter dry, fragile materials with these feeders

Schenck Process



DEA Weighbelt stainless-steel feeders (photo) provide weight-controlled feeding, weight indication and totalization for fragile materials. DEA Weighbelt feeders are offered in 12- and 24-in. belt widths with easy belt detensioning and removal, belt-weight influence compensation (BIC) and feedrate capabilities up to 1,680 ft^3/h. For sanitary environments, open-frame models of the DEA Weighbelt with washdown capabilities are also available. — *Schenck Process LLC, Whitewater, Wis.*
www.accuratefeeders.com

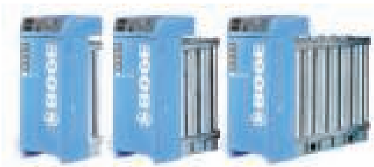
Compact AS-i modules save space in the control cabinet

Siemens

This company has developed extremely compact I/O (input/output) modules for AS-Interface (actuator-sensor interface; AS-i) with widths of just 17.5 and 22.5 mm. The new AS-i SlimLine compact modules (photo) are just half the width of the predecessor devices, and they save space in the control cabinet and in distributed control boxes. They possess new, practice-oriented functions, such as device connectors and switchable sensor supply, which surpass the previous functional scope. The 17.5-mm variants are said to be the slimmest AS-i modules currently on the market. The new series of AS-i SlimLine compact modules in degree of protection IP20 encompasses digital I/O modules as well as ASIsafe modules with safe inputs. It replaces the previous S22.5 and S45 Slim-

Hoyer GmbH Internationale Fachspedition

Wika Alexander Wiegand



Boge Kompressoren Otto Boge

Pepperl+Fuchs

Line modules. The new AS-i SlimLine compact modules supplement the product range of AS-i field modules and they are suitable for initial installation, servicing, or whenever a change or expansion is made in a plant. — *Siemens AG, Munich, Germany*
www.siemens.com

Two new small containers added to this company's product range

This logistics specialist has expanded its fleet of intermediate bulk containers (IBCs) by adding two new container types. The product range now also includes a steam-heatable IBC and a cube-shaped IBC (photo) that is particularly space-saving in storage and during transport. The steam-heatable 1,000-L container provides the ability to use steam, water or oil as the heating medium, thus ensuring heating that is quick but gentle on the material. It is also suitable for use in explosion-hazard areas and is designed for temperatures up to 150°C and pressures up to 6 bars. The cube-shaped Meter Cube has a volumetric capacity of 1,000 L and represents a practical alternative to a plastic IBC; the container is extremely space-saving due to its special dimensions, and it is made of high-quality stainless steel. As a result of its flat construction, it can also be stacked two-high for transportation, increasing the quantity of units that are possible per transport. — *Hoyer GmbH Internationale Fachspedition, Hamburg, Germany*
www.hoyer-group.com

In-house nitrogen production for maximum independence

The centerpiece of this company's line of closely tailored nitrogen-generating solutions is the N_2 generator selected from the N 7 P to N 56 P range (photo). Closely tailored to the N_2 demand, it delivers purity grades of up to 5.0 (99.999%). The generators can simply be connected to the existing compressed-air network. To produce N_2, the generators need a supply of Class 141 purified compressed air according to ISO 8573-1 (including activated-carbon adsorber). Thanks to its modular design, it is easy to expand or retrofit the generator on site. Up to two expansion banks can be connected to each master bank. Each bank, in turn, takes up to eight discrete easy-to-fit modules. The up to 24 modules that result provide flexible nitrogen generation of between 1.3 and 265.8 Nm^3/h. By combining even more of the complete systems, output can be increased to meet even higher demand. — *Boge Kompressoren Otto Boge GmbH & Co. KG, Bielefeld, Germany*
www.boge.de

Miniature thermometers now also with CSA seal of approval for Ex i

The intrinsically safe versions of the new miniature resistance thermometers — TR21, TR31 (OEM) and TR34 (photo) — now also have the CSA (Canadian Standards Association) test mark for ignition protection type Ex i. The seal of the CSA Group facilitates the use of thermometers in North America. In addition, all three instrument types have ATEX and IECEx approval. The new miniature thermometers are designed for use in industrial applications. Their design is extremely durable, and an autoclavable version is available for sanitary applications. All models are designed for a temperature range of –50 to 250°C. — *Wika Alexander Wiegand SE & Co. KG, Klingenberg, Germany*
www.wika.com

A new purge-and-pressurization solution for process automation

In demanding hazardous-location process environments, having realtime control of process applications is crucial. Set for release early this year, the Bebco 6500 Purge and Pressurization Series (photo) has been designed specifically for global Zone1/21 applications, and offers a control unit with HART and Bluetooth connection and communication. In addition, the 6500 vent provides continuous readouts of both pressure and flow for added monitoring functionality. A free mobile application is also available for smartphones or tablets that allows end users to easily link to the 6500 control unit. The control units are engineered in 316L stainless steel, and are available with either internal or external mounting options. — *Pepperl+Fuchs GmbH, Mannheim, Germany*
www.pepperl-fuchs.com ■

Mary Page Bailey and Gerald Ondrey

Weighing Equipment Selection

Department Editor: Scott Jenkins

The number of options available for scales and weighing equipment can make it difficult to determine which instruments will offer the best value and which will meet the application requirements (Table 1). Focusing on the following ten areas can help reduce the time needed to research available models and help ensure a good value.

1. Primary use. Identifying the instrument's primary use is the first step in selection. Will the instrument be used for weighing solids or liquids? Will the device be used at laboratory scale, or larger? Is it needed to weigh large quantities of uniformly sized objects, such as capsules, tablets or small parts? Will the instrument be used for weighing moving items on a production line? Do you need to control conditions inside a weighing vessel, such as heating, cooling or mixing?

2. Capacity. What is the largest possible load that a scale would be required to handle? Do you need overload protection? What will the overall footprint of the scale be and how will the items being weighed fit within the weighing area? Would a below-balance setup, where weight is measured via tension instead of compression, work for your application? An unofficial guideline recommends use of a balance for samples from microgram levels to approximately 10 kg, and load cells for those samples from 10 kg to several metric tons. Try to have the weighed quantities lie mostly in the middle of the range of the unit's specific capacity to minimize stress or damage to sensitive internal electronics, and also to ensure greater accuracy.

3. Accuracy. In the context of weighing, accuracy can be thought of as a combination of several different factors, including the quantifiable specifications of resolution (the smallest mass change that can be read on a scale), reproducibility (ability to weigh consistently over time and with different operators), linearity (the variance in accuracy over the weight values within the scale's capacity) and uncertainty of measurement (difference between measured weight and true weight due to environmental variances).

4. Materials of construction. Basic materials include aluminum alloy, carbon steel, aluminum-coated steel and galvanized steel. For these, cleanliness and corrosion-resistance are not critical. When higher levels of cleanability and chemical and environmental protection are required, AISI-304 and 316 stainless steels are possibilities.

5. Environment. Environmental conditions can affect weighing. Large temperature fluctuations, vibration, humidity, magnetic fields, air currents, corrosive chemicals and electrical interference can all influence weight measurements, especially at higher resolutions. Consider whether a particular environment would require specialized padding, protective covers, or more frequent calibrations.

6. Industry regulations. Many industry-specific regulations exist and may be relevant for some sectors and not others. Table 2 contains a list of websites for several of the organizations that set standards and regulations.

TABLE 1. INSTRUMENT CATEGORIES	
Simple scale	An appropriate vessel is placed on a weighing pan, the scale is tared accordingly, and a solid or liquid sample is placed into the vessel
Counting scale	A small known quantity of pieces is placed on the weighing pan. The scale calculates the average weight of these pieces and stores it in memory. Subsequent unknown quantities of the object are instantly calculated using this average weight no matter how many are placed on the pan. Results can be stored or printed for use in record-keeping and other documentation
Check-weigher	A checkweigher is the best scale for weighing moving items on a production line, where speed or the need for 100% inspection prohibits manual weighing. The device weighs each item on the production line according to preset detection limits, ejecting non-compliant items and even sorting items based on programmed user criteria. As each unit is inspected, overfilled and underfilled packages are identified and can be quickly rejected
Batch weighing systems	Scales designed for batch weighing incorporate a load cell, connections, valves, relay hardware and process-control software into one integrated system. This system is connected to and controls one or more feed systems that deliver different ingredients into a common receiving vessel at user-defined quantities to blend or create a reaction

TABLE 2. REGULATIONS AND STANDARDS WEBSITES	
FM Global	www.fmglobal.com
ATEX	ec.europa.eu/enterprise/atex
HACCP	www.fda.gov/food/GuidanceRegulation/HACCP/default.htm
IEC	www.iec.ch
ISO	www.iso.org
NEMA	www.nema.org
NTEP	www.ncwm.net/ntep
UL/CUL	www.ul.com
ETL	www.intertek-etlsemko.com
CSA	www.csa-international.org

7. Features. Additional features can customize the scale for enhanced flexibility, ease of use, functionality, protection and others. Consider whether your scale would need explosion protection, internal calibration software, interfacing ability with a computer network, wireless connectivity, scale readouts that are separated from the weighing platform, multi-language displays, backlit display for dimly lit areas, or other needs.

8. Price. Choosing a scale should never be based solely on price, but the most expensive scale is not necessarily the best choice.

9. Installation. When installing, it is recommended to place scales in a permanent location and connect to peripheral equipment, including a remote display. The resolution and readability should be set, and an initial calibration should be performed. For multiple load cells on a large vessel, a corner load test should be performed to ensure even weight distribution. Scales should generally not be moved from their point of use after installation, if possible.

10. Calibration and service. Regularly scheduled calibration of weighing equipment is necessary, because with use, normal stress can cause the accuracy of a scale to drift slightly. A series of certified test weights are placed on the weighing platform and the results recorded. When displayed results do not correspond to the test weight, manual or automatic adjustments can be made to correct the drift. ■

Editor's note: This column is adapted from the following article: Titmas, R. and Carey, S., Weighing Your Options: The 10 Most Important Scale Considerations. *Chem. Eng.*, December 2007, pp. 61–65.

Acrylic Acid Production via Propylene Oxidation

By Intratec Solutions

Acrylic acid is a moderately strong carboxylic acid primarily used as an intermediate in the production of acrylate esters. These acrylate esters are then mainly used to manufacture adhesives, plastics additives, coatings, paints and textiles.

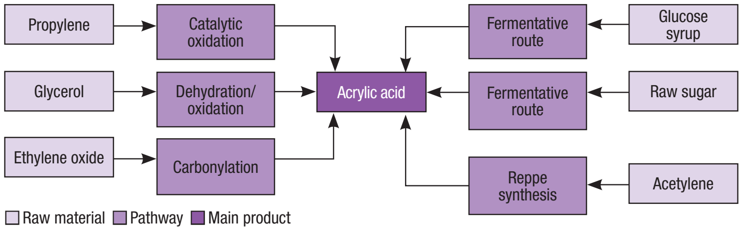


FIGURE 2. Several pathways exist for acrylic acid production

The process

Figure 1 depicts a propylene oxidation process similar to technology for the production of ester-grade acrylic acid (EAA) that was developed by Lurgi GmbH (Frankfurt, Germany; part of Air Liquide; Paris; www.airliquide.com) and Nippon Kayaku (Tokyo; www.nipponkayaku.co.jp). This process is described in the next paragraphs.

Reaction and quench. Chemical-grade (CG) propylene is mixed with steam and air and fed to a two-step oxidation reaction system. In the first step, the propylene is oxidized to acrolein and, in the second step, the acrolein is oxidized to acrylic acid. Both steps are carried out in tubular, fixed-bed reactors. The heat generated by the exothermic reactions is used to generate steam. The effluent from the reaction system is sent to a quench tower, where the acrylic acid formed is absorbed in water. Part of the residual gas obtained by the top of the quench tower is incinerated, with the balance being recycled to the first-step reactor. The aqueous solution is sent to downstream units for product recovery.

Product recovery. The aqueous solution from the quench step is fed to an extractor, where the acrylic acid is separated by liquid-liquid extraction with a solvent. The top portion of the extractor, containing the acrylic acid, is sent to a solvent-recovery column to recover a two-phase overheads stream. This two-phase stream is separated and the organic phase, containing the solvent, is recycled to the extractor. The aqueous phase is mixed with the raffinate from the extraction step and sent to a raffinate stripper to minimize the solvent losses. The bottom stream from the solvent-recovery column is then fed to the crude acrylic-acid column, where a concentrated acrylic acid stream is obtained as the bottom product. The column overhead stream, mainly comprised of acetic acid and light impurities, is sent to a recovery column. The bottom stream from the recovery column is sent to the crude acrylic acid column and the overhead stream is recycled to the solvent recovery column.

Purification. In the purification area, the concentrated acrylic acid stream from the crude acrylic acid column is fed to the product column. In this column, ester-grade acrylic acid is obtained as the overhead product. The column bottoms are sent to a dedimerizer to convert the dimer impurity, formed in the process, back to acrylic acid. Finally, the product from the dedimerizer is sent to the bottoms stripper column, where the heavy ends are separated and sent to waste.

Economic performance

The total fixed capital estimated to construct such a plant producing 150,000 metric tons per year of EAA in the second quarter of 2015 in the U.S. is about $350 million. The total fixed capital estimated includes the inside- and outside-battery limit units (production units, storage installations, utilities facilities and auxiliary buildings).

Acrylic acid pathways

Processes based on propylene oxidation are traditionally most employed in the production of acrylic acid. Figure 2 illustrates other alternative pathways for the production of acrylic acid, starting from different feedstocks. ■

Edited by Scott Jenkins

Editor's Note: The content for this column is supplied by Intratec Solutions LLC (Houston; www.intratec.us) and edited by *Chemical Engineering*. The analyses and models presented are prepared on the basis of publicly available and non-confidential information. The content represents the opinions of Intratec only. More information about the methodology for preparing analysis can be found, along with terms of use, at www.intratec.us/che.

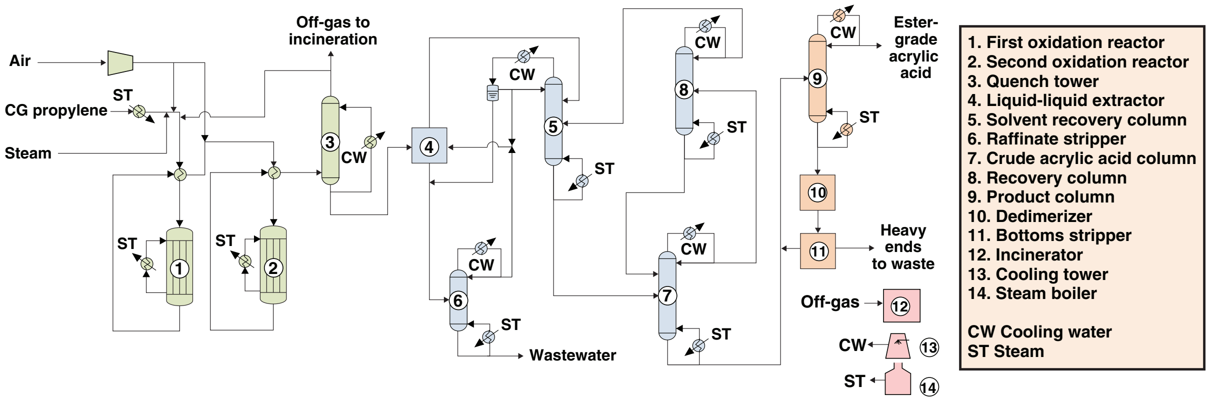


FIGURE 1. The diagram shows a process similar to the Lurgi/Nippon Kayaku technology for ester-grade acrylic acid production

Superheater Problems in Steam Generators

Knowing the features of a good boiler will prevent problems associated with a poor design

Viswanathan Ganapathy
Boiler Consultant

IN BRIEF

OVERVIEW OF THE PROBLEM

REASONS FOR TUBE FAILURE

THREE DECADES OF IMPROVEMENTS

TYPES OF SUPERHEATERS

CUSTOM-DESIGNED BOILERS

CONVECTIVE VERSUS RADIANT

FAILURE ANALYSIS

Oil- and gas-fired package steam generators (or boilers; Figure 1) are used in chemical plants, power plants, petroleum refineries and in cogeneration plants to generate steam for process and power-generation applications. Steam parameters are typically in the following ranges: steam flowrate, 40 to 200 ton/h; pressure, 30 to 100 barg; and temperatures, 350 to 500°C. A widespread problem in several plants is the failure of superheater tubes due to overheating and the reasons can often be traced to either poor design or poor operation, or a combination of the two.

Overview of the problem

In the author's opinion, based on his international boiler consulting experience over the last decade, poor design accounts for a significant number of problems. It should be kept in mind that the average life of a boiler, whose cost runs into millions of dollars, is more than thirty years, and a well-designed superheater also should last that long. If the plant personnel have to spend sleepless nights every few months fixing a poorly designed boiler that has frequent superheater tube failures, then it is an expensive nightmare they have purchased and not a steam generator.

Some plants are also, unfortunately, forced to operate their boilers at 40 to 60% capacity instead of at 100% as originally envisaged by them, because superheaters fail if operated at higher loads. This results in under-utilization of the boiler and significant financial losses, because the additional steam has to be generated from some other boiler or purchased from an expensive source.

Education of plant engineers is one way to ensure they become knowledgeable customers and don't purchase boilers without asking the boiler supplier the right questions. Hence, the author has also been conducting courses on boilers with

Cleaver Brooks

FIGURE 1. A package oil- and gas-fired, D-type boiler in shipment

emphasis on process and thermal design aspects and good features a boiler should have. These topics are somewhat grey to plant engineers, who are more familiar with mundane aspects of a boiler, such as maintenance, operation, repair, welding issues, refractory pouring, shipping and erection. Engineers tend to concentrate only on such issues before purchasing a boiler. However, only an engineer well versed in thermal design aspects can quiz the boiler supplier about the design details and performance to ensure the right design has been offered for purchase rather than a compromised design that can pose problems later. This is more easily said than done.

The author also advises plants to get a review of the steam generator design they plan to purchase from a good boiler consultant before they place the order so that potential problem areas are identified before the equipment is purchased.

One may wonder if boiler suppliers around the world are not offering well-designed steam generators. A few boiler suppliers still offer designs that are "dated" — designed 30 to 50 years ago — and are unwilling to improve or modify their design due to the significant engineering expenses and time involved in updating their older designs and preparing new drawings and standards. Also engineers well-versed in thermal and process design topics may not be available in every boiler supplier's company. Unfortunately, many boiler sales engineers still pull out drawings of a boiler sold 25–40 years ago (for similar parameters) from their archives and offer the dated design to unwitting plant engineers, who buy them without raising queries on thermal design and performance aspects, and live with superheater failures or under performance for the rest of their lives. I have seen this during the last twelve years of my international consulting experience.

This article briefly outlines the features of a good oil- and gas-fired steam generator, mainly of the D-type design, which is very common in the industry. The features of a good superheater design and thermal performance aspects that should be looked into are also discussed. The comments hold true for the other boiler designs, too, namely the A and O-type boilers.

Reasons for tube failures

There are several reasons for boiler superheater tube failures, including the following:

1. Use of radiant or semi-radiant superheater design exposed to high heat flux from a furnace with low steam-side velocity or low steam-side pressure drop; cross-flow or counter-flow design; oversizing, when steam temperature is around 400–500ºC
2. Carry-over of solids from the drum due to poorly designed drum internals or poor feed-water or boiler-water quality can result in deposition of solids inside superheater tubes and consequent overheating. Sometimes the drum size is smaller than it should be to prevent carryover of moisture. Load fluctuations leading to large fluctuations in steam pressure and drum level also cause carry-over of solids from drum
3. Burners not tuned properly can lead to flame impingement on the superheater. If several burners are used, certain combinations of burners may result in non-uniform gas flow or temperature distribution at the superheater inlet, leading to overheating of some tubes
4. Mechanical issues, such as thermal stresses, creep, stress corrosion, erosion (due to particulate matter in fluegas) and compromised tube metallurgy

As mentioned earlier, a large percentage of plant engineers, including the management, take it for granted when they buy a boiler that the boiler design itself is fine and the superheater tube failures are only due to operational problems. The following sections highlight the thermal design aspects with which plant engineers should be familiar to avoid selecting a boiler with dated design features or with poorly designed superheaters.

Three decades of improvements

Plant engineers should be familiar with some of the developments that have taken place during the last 30 to 40 years that have added value to steam generators in terms of thermal performance, operating costs and superheater life. If the boiler they are likely to buy does not have any of the features listed below, they can question the boiler supplier or opt for better boiler designs available in the market place.

Completely water-cooled furnace. The oil- and gas-fired steam generators designed 30 to 50 years ago did not have to deal with the problem of emissions regulations, particularly those due to oxides of nitrogen (NOx) and carbon monoxide. The only concern was efficiency, and oil- and gas-fired boilers were operating at 5 to 10% excess air.

Also, not much time was spent by many package-boiler companies in understanding issues such as DNB (departure from nucleate boiling), furnace effectiveness, furnace heat flux and circulation aspects. To protect the regions prone to high heat flux in the furnace and possible departure from nucleate boiling, they simply poured refractory over the areas such as the furnace floor, boiler front wall and in some regions on the partition wall. Some older designs still have a refractory-lined front wall, which makes it difficult to ensure a leak-proof furnace. Fluegas can leak to the atmosphere between the membrane side walls and refractory joints and if it contains vapors of sulfuric acid, this can condense on the casing to form sulfuric acid resulting in casing corrosion.

Not having a completely water-cooled furnace also results in underutilization of the furnace heating surface by 10 to 20% and an increase in furnace exit-gas temperature (FEGT). The higher the FEGT, the higher the direct radiation to the heating surface located at the furnace exit, namely the radiant superheater. Pouring refractory on furnace water-cooled surfaces is like buying a long-sleeved shirt in a department store and then going to a tailor and paying him additional money to make it a short-sleeve shirt. You are not only adding to the cost of the boiler, but also wasting a lot of labor and time on annual maintenance of refractory. Refrac-

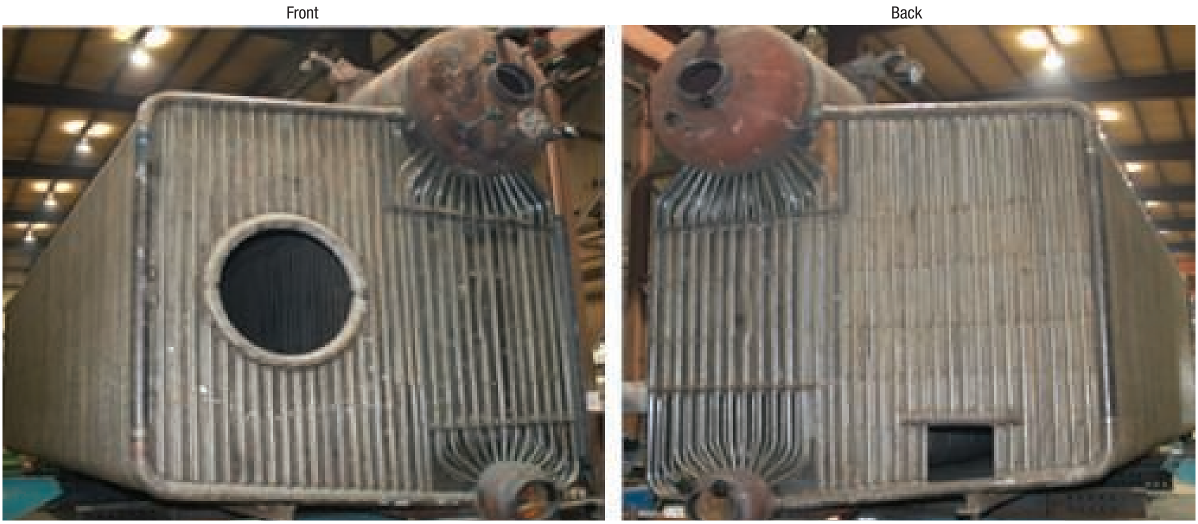


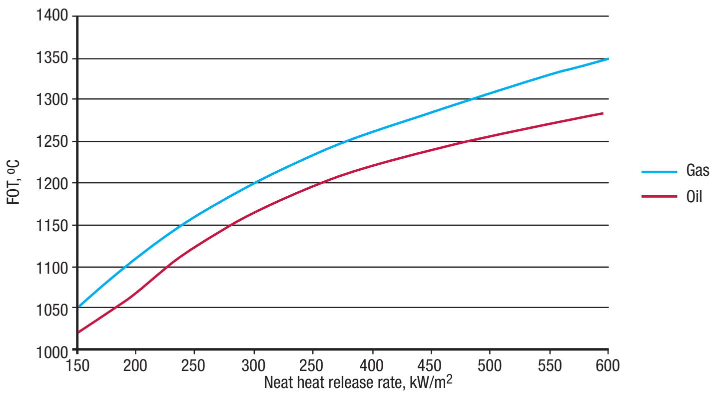
FIGURE 2. Completely water-cooled furnaces, such as the one shown here, help lower NOx emission and increase furnace effectiveness

tory-lined boilers have to be started up more slowly than a water-cooled furnace due to potential formation of cracks in the refractory if started up quickly.

The completely water-cooled furnace (Figure 2) has several advantages over refractory-lined boilers, such as lower NOx emission rates, better utilization of furnace surface and lower FEGT. This results in lower tube-wall temperatures in the heat transfer surfaces located downstream of the furnace, such as the superheater, which, as a result, enjoys longer life. The FEGT is lower due to the higher furnace effective area for a given volume of furnace; hence the ratio of net heat input to furnace divided by the effective furnace area is smaller (Figure 3) [*1*].

The refractory-lined front wall reradiates energy back to the flame, increasing its local temperatures and thus increasing the NOx levels. A furnace with water-cooled front wall, side walls and floor, as shown in Figure 2 (left), offers a benign enclosure to the flame and lowers the NOx emissions, besides lowering the heat flux and area heat-release rate.

FIGURE 3. This chart shows the effect of heat input divided by effective surface area versus FEGT [sometimes known as furnace outlet temperature (FOT)]



In order to meet NOx and CO emissions standards of today, steam generators widely use fluegas recirculation (FGR) ranging from 10 to 25% depending on the combustion temperature of the fuel and NOx emission limits; excess air ranges from 12 to 18% to limit the CO emissions in natural-gas- and oil-fired boilers. In a completely water-cooled furnace that offers a cooler enclosure all around the flame, the NOx emissions are lower compared to a refractory-lined boiler. Refractory used in the front wall and areas close to the floor and side walls reradiates energy back to the flame, increasing NOx formation. Hence lower FGR is required to limit the NOx in a fully water-cooled furnace compared to the refractory-lined boiler.

Higher excess air and FGR simply increase the fluegas mass flow through the boiler for the same steam parameters, thus increasing the fan power consumption. Remember that the size of a boiler depends on the fluegas quantity handled by the boiler heating surfaces and not the steam parameters. Custom-designed boiler manufacturers consider this fact and redesign their heating surfaces (by changing tube spacing, increasing the size of economizer) and ensure high efficiency and low fluegas pressure drop through the unit. Unfortunately, a few boiler suppliers still offer standard, off-the-shelf designs selected based on steam parameters alone, which will have lower efficiency or higher fan power consumption if FGR has to be used.

Convective superheater design versus radiant superheater. Superheaters of boilers designed decades ago were located at the furnace exit, irrespective of steam temperature required; the superheater was in the radiant zone and hence exposed to high heat flux and direct radiation from the furnace flame, resulting often in tube failures (Figure 4A). These superheaters were called radiant superheaters. There is another option where the superheater is located in the convection bank itself, but without a screen. This is called a semi-radiant superheater (Figure 4B). Present-day designs from a few boiler suppliers who specialize in custom-designed units, have convective superheaters with a large screen section, shielding it from direct furnace radiation (Figure 4C).

A radiant superheater is not good choice for package boilers and is better avoided because the superheater is located in a harsh environment. A radiant superheater receives radiant energy from the furnace flame, while a convective superheater is shielded from furnace radiation because it is located in a much cooler region behind several rows of screen (evaporator) tubes.

A number of factors impact the design and thermal performance of semi-radiant or radiant superheaters and boiler plant engineers must be aware of them. Only then can they appreciate the fact that they are buying a design with great potential for tube overheating and failures.

1. It is difficult to estimate the FEGT accurately. A good boiler designer knows this. Variations in fuel analysis, excess air, furnace geometry, burner location and flame shape to mention a few, affect the FEGT, which in turn directly affects the superheater duty and tube wall temperature. The correlations for furnace performance are not clearly established (like the convective heat-transfer-coefficient correlations for fluid flow inside or outside tubes, which you can see in any textbook on heat transfer). FEGT is mainly established based on field data of similar boiler designs and operating data. Variations of 50–120°C are likely in its estimation, which can affect the energy transfer to the superheater and its tube wall temperature. The external radiation energy transferred to the superheater tubes will also be proportional to the FEGT to the power of four. One can appreciate the problem if, while estimating the FEGT, the designer comes up with a value like 1,000°C while in operation it is close to 1,100°C. The direct radiation will be higher by 35% [$(1{,}373)^4$ versus $(1{,}273)^4$]. The logarithmic mean temperature difference (LMTD) in the superheater also will be affected, resulting in some uncertainty in the duty and performance evaluation of the superheater. A higher LMTD than estimated will not only increase the duty of the superheater but will also increase the heat flux and the tube wall temperature.
2. A semi-radiant superheater receives direct radiation from the furnace and depending on the tube spacing-to-diameter ratio, the fraction of energy absorbed in each row will vary (Figure 5). If the superheater tubes are closely spaced, then more direct radiation

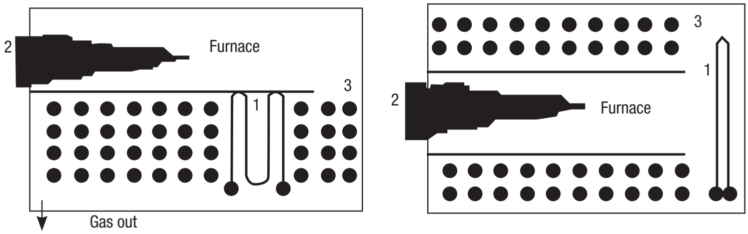


FIGURE 4A. Depending on its location, a superheater can be either convective (left) or radiant (right). The numbers identify the superheater (1), burner (2) and screen, evaporator (3)

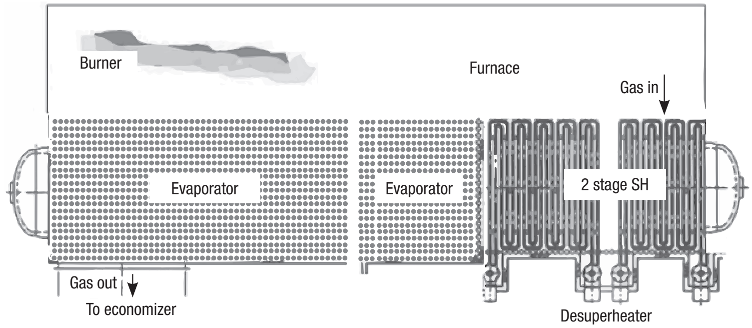


FIGURE 4B. A semi-radiant superheater without a screen section is shown here

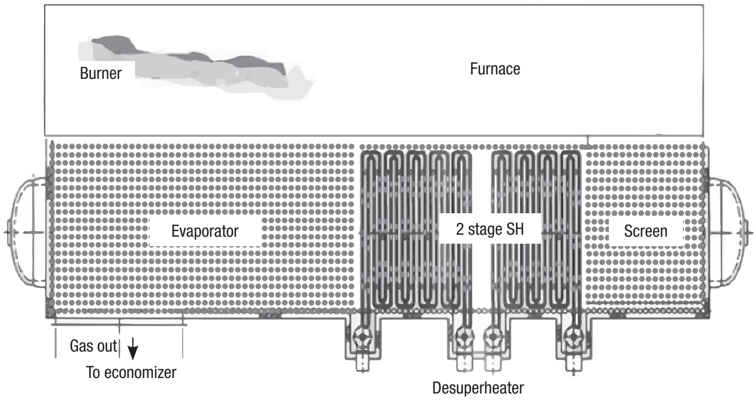


FIGURE 4C. Shown here is a convective superheater with vertical headers and horizontal tubes located beyond the screen section

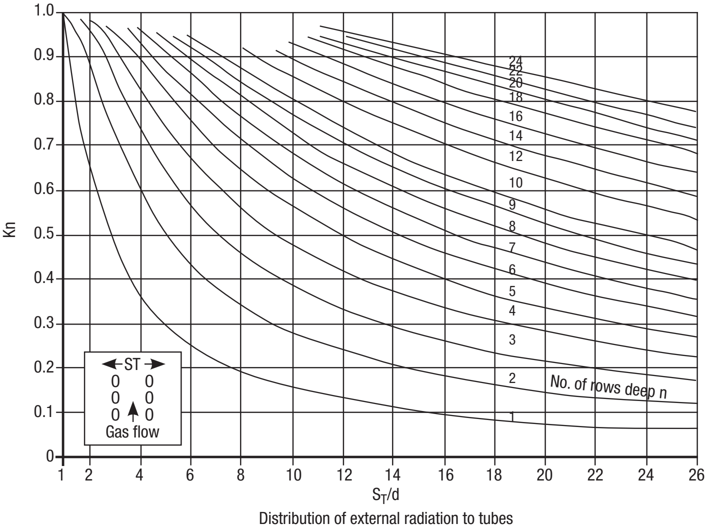


FIGURE 5. This chart shows the distribution of external radiation from furnace to heating surfaces at the furnace exit (Kn is fraction of direct radiation absorbed by each row and S_T is the transverse spacing of tubes)

will be absorbed by the superheater in the first two to three rows facing the furnace, thus increasing the tube wall temperature in these rows. Typically four to five rows of tubes absorb the complete external radiation, as seen from the chart in Figure 5. This adds to the heat flux inside the superheater tubes. Typically the tube wall temperature can go up by 20 to 40°C due to external radiation; at tube wall operating temperatures close to 600–650°C, even a 10°C increase can result in tube failure. At partial loads, the increase in tube wall temperature will be higher, as shown in some worked out examples in Ref. 1.

3. With uncertainty in the estimation of FEGT, the direct radiation from furnace to the superheater is also difficult to predict. While evaluating the tube wall temperature in the superheater, one has to add the heat flux arising out of direct radiation, convection and non-luminous radiation. The contribution of direct radiation is a function of the location of the tube facing the opening and the tube spacing as shown in Figure 5. It can be seen that when the tube spacing to the convection bank is large, a large amount of energy is sent to the next row and so on. The radiant superheater also absorbs more enthalpy at partial loads compared to full load. At low loads, the flow distribution on both gas and steam side will be poor. Hence tube overheating is likely at all loads [*1*].
4. The turning section where the superheater is located adds to non-uniformity in gas flow, velocity and temperature profiles across the superheater, making it difficult to predict its performance. A portion of the superheater can have cross flow and a portion can have parallel flow and the fraction of each can vary with load. Thus its performance prediction becomes a guessing game. One is taking chances with such a location for the superheater.
5. If the flame shape is not properly set, the flame can lick the first few rows of superheater facing the furnace. Since the heat-transfer coefficient is much lower inside a superheater tube (about 6 to 10 times lower than that of the evaporator or furnace tubes), the increase in tube wall temperature can be high, leading to tube failures.
6. On the other hand, the convective superheater is located in a safe region far away from the furnace outlet. The number of screen rows (the function of screen tubes is the same as that of the evaporator) can be as high as 10 to even 40 rows depending on steam temperature desired. There are three advantages of using a screen section. One, the gas temperature drops significantly before entering the superheater say by 250–500°F (depending on the number of screen rows) and the heat flux inside the tubes is significantly lower compared to the radiant design. The second is that the fluegas mixes well beyond the turn and becomes uniform before entering the superheater due to the gas pressure drop in the screen section, and hence the prediction of superheater performance is far more reliable, unlike the situation for a radiant superheater. Thirdly, the direct radiation contribution from the furnace is also avoided as the screen or evaporator tubes pick up the direct radiation and since the screen or evaporator tubes have a high-boiling heat-transfer coefficient inside the tubes (exceeding 2,500 Btu/ft^{2}h°F compared to 200–350 Btu/ft^{2}h°F for the superheater), the evaporator tube wall temperature increase is not a concern at all.
7. A major advantage for the convective superheater is its lower tube-wall temperature, which results in a longer life compared to the radiant superheater. This is due to the lower gas-entering temperature and absence of direct radiation. A simplistic tube life calculation below illustrates this point.
8. In heavy-oil-fired boilers, the slag formed due to the melting of ash in fuel oil can deposit on a radiant superheater, which is operating at high temperature and can cause high-temperature corrosion failures,

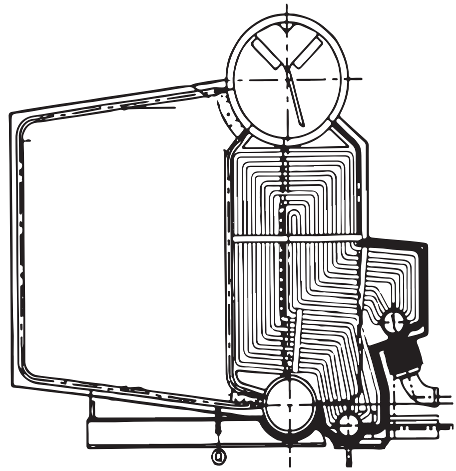


FIGURE 6A. Shown here is a superheater with a vertical tube of inverted loop design

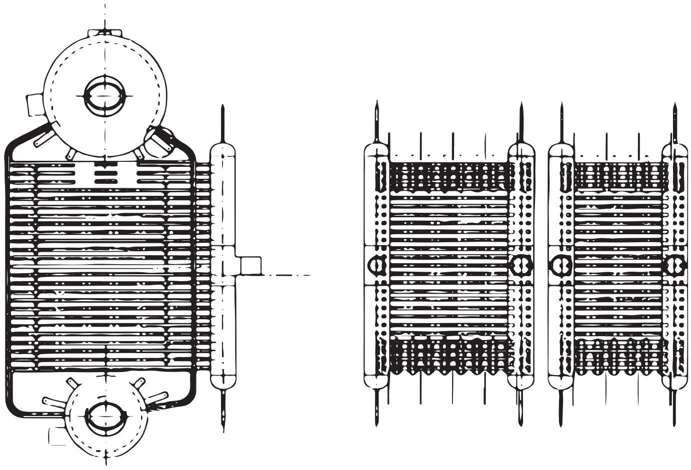


FIGURE 6B. Two different views of a superheater with a horizontal tube design

mainly due to vanadium, sodium salts and their compounds. The convective superheater can be located where fluegas temperatures are far below the slagging temperature.

9. Variations in excess air, flame shape or FGR will have a lesser effect on steam temperature in a convective superheater due to the additional cooling and mixing in the screen section ahead of the superheater.
10. The boiler can be started up faster because the gas temperature entering the superheater will be much lower in a convective design compared to the radiant design. If the guideline is, say, 600ºC maximum at the superheater, then it takes less time to reach this temperature with a convective superheater. A boiler with a radiant superheater has to be started up more slowly to ensure that 550–600ºC is not reached at the superheater before steam starts flowing through the superheater.

Hence the radiant or semi-radiant superheater design should be avoided if possible for a longer life of superheater and trouble-free operation as it poses more risks compared to a convective superheater.

This is not to say that all boilers with radiant superheaters will have problems in operation. Good radiant superheaters are designed with better materials, steam flow arrangement (referring to whether it is the primary or intermediate stage of superheating, and flow direction, whether parallel or counter flow) and high tube-side mass velocities and steam-side pressure drops to ensure trouble-free operation, but it is an unnecessary risk for steam temperatures up to 500ºC. High-pressure, high-temperature utility boilers, which operate at 165 kg/cm^{2}g and 540–550ºC with reheat require radiant designs as superheaters, and have to be located in high gas-temperature regions for compactness. But package boilers operating at much lower steam pressures need not have radiant or semi-radiant superheaters. The author has designed several hundred units with fully convective type superheaters which are in operation around the world without problems since 1990. The only advantage of radiant design is that some surface area is reduced and hence labor costs are lower for superheater fabrication, but materials are costlier, and shorter life and frequent failures and repair costs more than compensate for this small advantage.

Types of superheaters

Basically two types of superheater designs are available for package boilers and are widely used. One is the inverted loop superheater (Figure 6A), and the other is the horizontal tube superheater (Figure 6B).

Inverted loop. In the inverted loop design, the inlet and exit steam headers are horizontal and located inside or outside the gas path; baffle plates are used at appropriate places in the header to obtain the necessary number of streams (or tubes carrying the total steam flow) in order to optimize the steam-side pressure drop. If 100,000 lb/h is the steam flowrate and there are six tubes on each header (12 across the boiler bank width) and, say, 20 rows deep (along gas flow direction) and

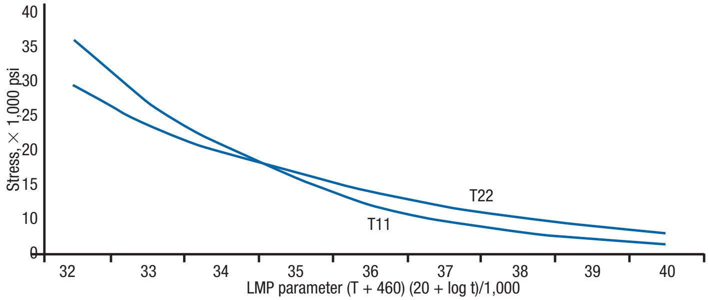


FIGURE 7. This plot of stress versus LMP for T11,T22 materials is useful for predicting the life of a superheater (*T* is the temperature in °F, *t* the life in h, and LMP is the Larson Miller Parameter [*1*])

24 streams are required to meet the velocity and pressure drop considerations, then there will be a baffle after the 4th row in the inlet header (6 × 4 = 24 streams), after the 8th row in the outlet header, after the 12th row in the inlet header and so on. Selection of streams for the superheater is a very important task and many superheater failures have been attributed to a wrong selection of this parameter [*2*].

Horizontal tube. In the horizontal-tube superheater design, vertical headers are used; the number of tubes in each row (or a multiple of it) can be the number of streams. Central inlet and exit nozzles are preferred for steam inlet or exit.

A superheater configuration can be parallel-flow or counter-flow or cross-flow and with single or multi-stages with intermediate desuperheating for steam temperature control. Performance calculations will reveal the best option for the superheater and are done on a case-by-case basis, as illustrated in examples in the references.

Custom designed boilers

The concept of custom-designed boilers started evolving around the 1980s when emissions of NOx and CO were regulated and new boilers were required to adhere to limits on these pollutants. Fluegas recirculation was one method used to limit NOx and excess air and low-NOx burners with staged combustion were introduced. Even today, several boiler suppliers offer what are called "standard, off-the-shelf package boilers" with low cost. However, a few boiler suppliers also offer what are called custom-designed boilers, which consider the impact of fluegas flow on boiler performance and optimize the design for lower operating cost and better efficiency. This is done by manipulating the boiler bank spacing, length of evaporator tubes, superheater location, number of screen tubes, economizer fin optimization and so on. Custom-designed units can lower fan power consumption and also ensure long superheater life. When the degree of steam superheat is, say, only 5 to 10°C, the superheater may be located between the evaporator and economizer. A great flexibility thus exists in custom-designed boilers. The author is even aware of a case where a customer wanted only 20°C of superheat and the boiler supplier had no idea how to handle such a low degree of superheat and suggested to the plant to purchase a separately fired superheater. This clearly shows that not many boiler suppliers can custom-design boilers for a difficult and challenging boiler application.

Several examples of custom-designed boiler applications that have created value for end users may be seen in the references cited. A standard off-the-shelf boiler is like a ready-made garment, it may fit you well or not, whereas a custom-designed boiler is

TABLE 1. TUBE GEOMETRY OF BOILER WITH RADIANT SUPERHEATER

Section	Screen	Superheater	Evaporator	Economizer
Tube OD, in.	2.0	2.0	2.0	2
Thickness, in.	0.120	0.200	0.120	0.120
Tubes/row	12	12	12	16
Rows deep	2	16	72	12
Length, ft	9	8.5	9	15
Transverse pitch, in.	5	4.8	5	4
Longitudinal pitch	4	4	4	4
Streams		24		8
Material	Sa 178a	T22	Sa 178a	Sa 178a
Flow direction		Counter		Counter
Fins/in. × height × thickness				5 × 0.75 × 0.05
Surface area, ft^2	113	855	4,072	16,417

TABLE 2. TUBE GEOMETRY OF BOILER WITH CONVECTIVE SUPERHEATER

Section	Screen	Superheater	Evaporator	Economizer
Tube OD, in	2.0	2.0	2.0	2
Thickness, in	0.120	0.15	0.120	0.12
Tubes/row	12	12	12	16
Rows deep	13	24	53	12
Length, ft	9	8.5	9	15
Transverse pitch, in	5	4.8	5	4
Longitudinal pitch	4	4	4	4
Streams		24		8
Material	Sa 178a	T22	Sa 178a	Sa 178a
Flow direction		Counter		Counter
Fins/in × height × thickness				5 × 0.75 × 0.05
Surface area, ft^2	735	1,065	2,997	16,417

like a tailor-made dress that fits perfectly.

Designs of standard boilers were developed several decades ago when there were no emission regulations. As mentioned earlier The FGR and excess air rates will vary with type of fuel, combustion temperature, NOx and CO emission limits, and hence, two boilers with identical steam parameters may differ in size depending on the total fluegas quantity flowing through the unit. Standard boiler suppliers have fewer options to choose from and one has to carefully review the efficiency, fan power consumption and overall performance.

Convective versus radiant superheaters

In order to understand how boilers with radiant versus convective superheaters differ in performance, an example is now presented.

Design and operating parameters. A boiler is designed to deliver 137,000 lb/h of steam at 720 psig and 800ºF, with a feedwater temperature of 230ºF. Fuel is natural gas (90% methane, 5% ethane and 5% nitrogen). Tables 1 and 2 show the tube geometry that is used for both designs. The radiant superheater is located at the turning section as shown in Figure 4B, while the convective superheater is located several rows downstream of the screen section (Figure 4C). The superheated steam temperature is uncontrolled as variations up to ±20°F are accepted by the plant. Furnace dimensions are the same for both options, namely 30-ft long, 8.5-ft high and 7-ft wide, and is a completely water-cooled furnace. The same economizer is used in both options. The only difference is in the tube thickness of the superheater and the number of rows of screen and evaporator. Excess air used is 15% and no fluegas recirculation is used in the basic design. The same boiler is likely to operate with 20% fluegas recirculation (FGR) later. The performance for both designs was calculated and the results are presented in Table 3 (Design and off-design calculation methods for superheaters and tube-wall temperature are detailed in Ref. 2).

Discussions on the two designs. The following points may be noted from Table 3.

1. Though the steam temperature is nearly the same at 100% load for both the radiant and convective designs, the tube wall temperature for the radiant design is about 1,085ºF versus 1,020ºF for the convective design. This is due to the higher gas temperature (nearly 400ºF) entering the radiant superheater and with some contribution from direct radiation from the furnace. By using a slightly higher tube thickness, the same superheater material can be used for both the radiant and convective design.
2. The life of the superheater is significantly reduced due to an increase in tube wall temperature. Let us estimate the life assuming the boiler operates at 100% load all the time. Figure 7, showing the stress versus Larson Miller Parameter (LMP), is used to estimate the life [*1*].

First estimate the operating stress, which is given by the relation: Stress = pressure × radius/thickness.

For the radiant superheater: Stress = 720 × 1/0.2 = 3,600 psi. From Figure 6, the LMP corresponding to this value is 39. The absolute tube-wall temperature is found by T = 1,085 + 460 = 1,545ºR. 39,000/1,545 = 25.24 = (20 + log t) or t = 174,000 h or about 22 yr.

For the convective superheater: Stress = 720 × 1/0.15 = 4,800 psi. LMP = 38.3. T = 1,020 + 460=1,480°R. 38,300/1,480 = 25.87 = (20 + log t) or t=743,000 h or more than 92 yr.

Though this is a simplistic method of estimation of potential lifespan, it shows that the life of the convective design is much longer than that of the radiant design, due to the lower operating temperatures.

3. The surface area of the convective superheater is much larger and hence costlier, but considering the low operating tube-wall temperature, it is considered a better design. The author has seen several superheaters with radiant design fail in a short period due to overheating. Frequent repairs and shutdowns are expensive and impacts the cost of business. As mentioned earlier, there are non-uniformities in gas temperatures and fluegas flows entering the superheater, particularly if it

TABLE 3. PERFORMANCE OF BOILER WITH AND WITHOUT FGR

Item	Radiant superheater	Convective superheater	Radiant superheater	Convective superheater
Excess air,%	15	15	15	15
Fluegas Recirculation rate,%	0	0	20	20
Steam temp. at 100% load,±10ºF	807	812	777	800
SH tube wall temperature, ±10ºF	1,085	1,020	1,030	990
Gas temp to superheater, ±10ºF	2,379	1,980	2,138	1,828
Gas temp to evaporator, ±10ºF	1,897	1478	1,762	1,420
Gas temp to economizer, ,±10ºF	795	823	809	834
Gas temp leaving eco, ,±10ºF	300	300	320	324
Efficiency, % HHV	84.27	84.27	83.6	83.5
Steam temperature@ 50% load	815	767	814	785

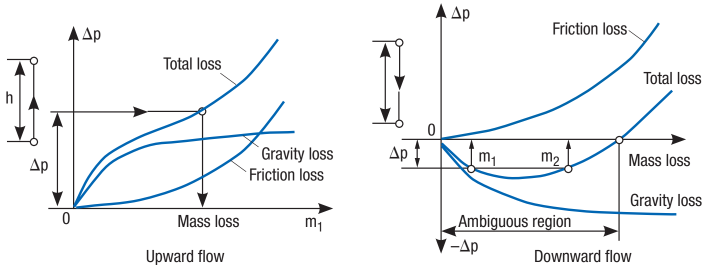


FIGURE 8. Flow versus pressure drop in upward- and downward-flowing tubes

is located at the turning section. Hence, prediction of its performance and tube wall temperature is less accurate compared to that of the convective design. When buying new boilers, plant engineers should give preference to designs with convective superheaters and be aware of the likely problems with a radiant design. At partial loads, the steam flow inside the tubes also will have a non-uniformity due to low steam pressure drop and this can also add to the increase in tube wall temperature in certain tubes.

4. Effect of adding FGR: As far as the steam temperature is concerned, the variation in steam temperature is much larger between 100 and 50% loads with a radiant superheater compared to the convective design, where the screen section dampens the large variations in fluegas flow and temperature.

Failure analysis

The author was asked to investigate frequent tube-failure problems in an inverted-loop superheater with cross-flow design as shown in Figure 6A. This boiler could neither be operated near 90–100% load nor at lower than 40% load, as tube failures would occur. This is a poor superheater design to start with and the author would have advised the plant against purchasing this boiler and to go for a design with a convective superheater. There were a few major concerns with this design:

- Superheater location is at the turn around section at the furnace exit with uncertain gas flow pattern and non-uniformity in fluegas flow and gas temperatures
- It is a single-pass cross-flow design with low steam-mass velocity inside the tubes and hence low steam-side pressure drop
- The superheater is facing the furnace and hence has direct radiation from the furnace in addition to convective and non-luminous heat fluxes
- Low steam-side pressure drop impacts the downward flow of steam in long tubes, as explained below

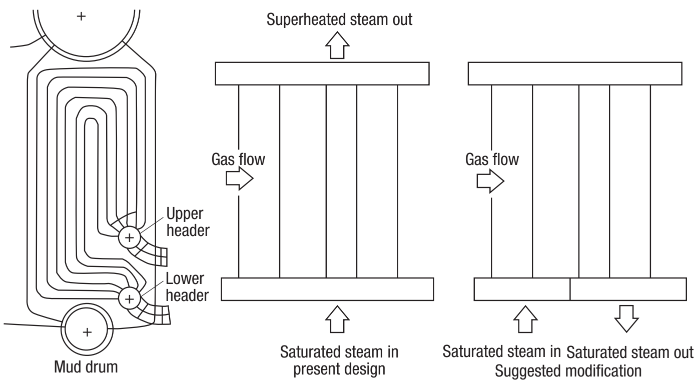
One of the problems with tall inverted-loop superheaters is the effect of steam-side pressure drop at low loads as shown in Figure 8 when steam flow is in the vertical downward direction.

When steam flows upward, both the gravity loss and friction loss are additive and hence their sum is always positive and the total pressure loss versus flow curve is monotonic [*2*].

In the downward flow section, at low loads, the enthalpy pick up will be higher in a radiant superheater compared to a convective one (due to the contribution of furnace radiation) and the density of steam decreases and hence lower gravity loss. As steam flow increases, the specific volume reaches a steady value and the steam density also will be higher while friction loss increases as the square of flow. The total loss curve will have two operating points as shown at low loads while at higher loads the total loss curve is monotonic and hence stagnation is not a concern. This trend is exhibited with a convective superheater also, but due to lower gas temperatures at lower loads, the tubes are much safer. Hence superheaters of inverted-loop design should be designed with a reasonably high steam-side pressure drop, which ensures gravity loss is not low enough at low loads to cause flow stagnation or ambiguity in flow. A "safe" pressure drop is arrived at in the design stage at 100% load based on steam pressure, height of superheater tubes and steam pressure. One has to also perform partial-load calculations and ensure flow stagnation will not be an issue. Unfortunately, many boiler designers do not understand this, and design superheaters with a low steam-side pressure drop resulting in tube failures at low loads.

Solution. Nothing much could be done about the location of the superheater. It was determined through calculations that the

FIGURE 9. The problem of tube failures discussed in the text was solved with baffles and a parallel flow design



superheater was designed with a low steam pressure drop resulting in overheating of the tubes over a wide load range due to a low tube-side heat-transfer coefficient and direct radiation from the furnace. At lower loads, the problem became worse, as there was stagnation in some tubes due to the gravity head loss being higher than the steam pressure drop, as explained earlier. The boiler could be operated only in a narrow range of load and even then tube failures were rampant.

The author reviewed the design and introduced a baffle in the inlet header, thereby making the superheater a two-pass design with parallel flow configuration (Figure 9). This modification brought in several advantages.

1. The steam-side pressure drop increased eight times, which was still acceptable to the plant. The cooling effect of steam was much better and there were no concerns about stagnation at low loads.
2. The parallel flow configuration took away the higher steam temperature region into the cooler gas-temperature region, thus limiting the tube wall temperatures.

However, it should be noted that to begin with, the design could have been avoided. The best option would have been to purchase a convective superheater with a large screen section with several advantages as cited earlier.

Concluding remarks

Plants invest several million dollars in steam generators and should review if a particular design is good in the long run. Even if the superheater runs well, the higher tube wall temperature limits the life as shown earlier. A convective superheater design should be preferred. Though the steam generator may be slightly more expensive, it pays off in the long run due to lower maintenance and repair costs. Plants should also hire a consultant to review the boiler design from a thermal and process viewpoint instead of simply taking the boiler suppliers' words for granted. Plant engineers should look at designs of custom-designed boilers and learn about their features and advantages and not simply buy a boiler because the same design has been offered by the boiler company for five decades. ■

Edited by Gerald Ondrey

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Author

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Feature Report

The Relationship Between Materials Selection and Machining Processes

An awareness of the impact of materials selection on the machining processes for small, complex components can affect overall end-product quality and costs

Kenneth Rinier
Vallorbs Jewel Co.

IN BRIEF

MATERIAL SELECTION FACTORS

THREADED PARTS AND VALVES

MACHINING SPECIFICATION

MACHINING SOLUTIONS

FIGURE 1. There are many implications for materials selection of threaded parts, especially when the machining process is considered

The importance of material selection for small, complex components found in equipment critical to the chemical process industries (CPI) cannot be understated. For small metal parts, such as valves and threaded fasteners, the steps product engineers take for selecting a material are fairly linear. The engineer determines the functionality and the operating environment of the components and chooses the material. Environmental factors taken into consideration include corrosion resistance, exposure to harsh chemicals and extreme temperatures. After evaluating the material based on these conditions, design engineers often make the final material decision for the specific part. However, the desired material may have certain properties that can present challenges in operation and machining, and the designer may not be aware of the potential issues that can arise.

There is an important relationship between material selection and precision, ease of machining and final finish that is often overlooked. These factors can have significant effects on the quality and cost of the component in question. The use of an ineffective machining method for small components can cause issues in certain materials, especially if they are exotic or hard-to-machine metals. These issues include fouled operating environments, premature component failure and oxidation effects, and are sometimes the result of inadequate machining and material selection. This article provides guidance to help design engineers consider the relationship between material selection, existing machining processes and the quality and cost of the end product.

Material selection factors

Functionality in the operating environment is generally a high priority for material selection of components, especially when it comes to the long- and short-term safety and reliability of the equipment. The following sections introduce some important factors that must be considered in material selection for small, complex components.

Corrosion resistance. Corrosion is a major concern that dictates material selection in many operating environments. For example, chloride ions cause stress corrosion cracking (SCC) in stainless steels, so a material like titanium is selected because of its chloride-resistant properties. These factors are critical because corrosion in equipment can result in a number of negative effects, including fires, explosions and both brittle and mechanical failures, as well as the release of hazardous gases, liquids or vapors.

Oxidation is commonly observed in materials like the stainless-steel alloys. These metals naturally form oxide layers for corrosion protection, which can cause uneven surfaces. This occurrence requires passivation treatment to reduce the negative effects of these oxide layers and to keep the surfaces smooth and free of imperfections that can cause equipment failure.

Exposure to chemicals. Materials can have adverse reactions to chemicals in various environments. Environmental chemical factors can include high acidity and the presence of oxygen or aqueous solutions, or even harsh cleaning or sanitizing agents. Although the production environment may be non-corrosive, the presence of these chemicals can cause materials to react, so a designer should consider the risks when selecting materials.

Temperature resistance. The engineer should be aware that the mechanical limits of materials can be negatively affected by high temperatures, potentially causing thermal failure or deformation. Materials are also selected based on temperature resistance because the effect of extreme temperatures on materials can cause increased corrosion rates. High-temperature materials include iron-, nickel- and cobalt-based metal alloys.

Cost. A major factor in the materials-selection decision typically involves the initial cost of the material, the ease of machining and repair and the availability of the material. Cost influences the balance between materials and machining in the case of material grades. For example, if an engineer chooses Inconel as the material for the product, the grade affects the machining cost. Since Inconel 600 is much easier to machine than Inconel 718, the time and cost of machining can change considerably depending on which grade is chosen. Figure 1 shows some threaded parts that are constructed of Inconel 718. However, note that cost is usually secondary to the other considerations that involve consistent and reliable operation of the part in its application.

Restrictive applications. In most CPI applications, the selection of the appropriate material can usually prevent the negative effects associated with the operating environment, but some applications are more restrictive. Due to strict operating-environment protocols, designing parts for certain applications, such as nuclear processing, can be limiting when it comes to choosing a material. Areas at risk for fire or explosions, such as oil-and-gas processing facilities, are also restrictive when considering equipment material. Certification systems, such as the International Electrotechnical Commission's (IEC; Geneva, Switzerland; www.iec.ch) globally recognized System for Certification to Standards Relating to Equipment for Use in Explosive Atmospheres (IECEx System; www.iecex.com), may require the provision of specific material properties to improve equipment and personnel safety.

The most common class of materials chosen for chemical processing equipment is metal, because metal materials are typically stronger, more resistant to fatigue and cracking, and are typically easier to machine than other material classes, such as glasses, polymers and ceramics.

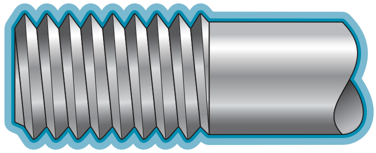


FIGURE 2. Threaded parts must be able to withstand a number of harsh conditions in CPI applications, including exposure to corrosive materials, high temperatures and pressures and other environmental restrictions

For small threaded parts (such as threaded valve connectors) that play a significant role in the performance and longevity of chemical processing equipment, metals are most often selected for these properties. However, in some precision equipment, such as gears, ceramics and other hard materials are corrosion-resistant and can achieve equal or better surface finishes than some metals. Other non-metallic materials, such as high-performance polymers, are used in place of metals to reduce the weight of equipment.

Threaded parts and valves

Threaded parts (Figure 2) and valves are used in processing equipment in countless CPI applications, but can often be overlooked. An understanding of these complex parts gives engineers insight into the materials-selection and machining processes.

Fasteners and threads. Fasteners and threaded parts can be the smallest parts in chemical processing equipment, but are often critical to the assembly of larger equipment. These components must be strong, durable and corrosion-resistant to ensure that equipment performs safely and reliably. As mentioned, exotic metals, including stainless-steel alloys, titanium and Inconel, which have greater resistance to harsh chemicals and can endure very high temperatures, are examples of desirable materials for fasteners used in heat exchangers, exhaust systems, tanks, vessels and other processing equipment. Mechanical properties, such as high strength-to-weight ratios, will also lead a designer to choose an exotic metal.

Valves. Valves are highly involved in chemical processing equipment, such as the piping systems that

FIGURE 3. Stainless steel provides many beneficial properties for valve internals, but this material can pose challenges for machining processes

control the flow of liquids, gases and vapors. Valve systems can be very complex, with multiple parts and components, and each one must perform as expected by resisting corrosion and fatigue. In harsh chemical-processing applications, valve systems are often custom designed to maintain pressure levels and prevent dangerous, and sometimes lethal, fugitive emissions. The control of fugitive emissions, no matter how small, is a major concern for plant engineers because they can be harmful to personnel, equipment and the environment.

Many of the basic external and internal components of a valve system depend on strong and tight threaded joints and connections for safe, reliable and efficient performance under demanding operating environments. An example of a threaded component in a valve is the valve body. Valve bodies make up the structural foundation and contain the internal components of most pressure valves. They are connected to piping via threaded or welded joints. The body is commonly attached to the valve bonnet with threaded connections. The bonnet houses the valve stem. Valve stems are typically attached to a disk (or ball, depending on the valve type) via threads. As the threaded stem spins into or out of the valve bonnet, the disk moves, controlling the chemical flow. The seal between the stem and disk must be tight, and uniform thread finishes are important to prevent leaks.

To ensure peak performance of these complex components, exotic metals are chosen. However, the selection of these exotic metals can present additional design challenges related to machining that design engineers are often unaware of that can negatively impact product quality and inadvertently drive up costs. Figure 3 depicts internal components from a high-pressure gas valve that are constructed of 316 stainless steel.

Machining specification

For threaded parts, it is common for design engineers to leave the machining method unspecified on a request for quote (RFQ) or design specification. The method is then left up to the machine shop to decide, which can result in missed opportunities for the designer to avoid premature failure, improve product quality and reduce costs, especially if the selected materials are difficult to machine. Knowing the available machining options can help a designer to make the most appropriate design choices.

Machining method options. The two most common methods for the machining of external and internal threads are cutting and rolling. Thread cutting is a process in which a sharpened cutting tool is used to physically remove material from a blank, metal round bar or hole to form threads. This results in the production of rough, uneven threads with microscopic chips that can flake off and foul the operating environment or cause excessive friction.

Thread rolling is a work-hardening process in which flat or cylindrical dies apply great amounts of pressure to the blank material, forcing the material outward into the shape of threads. Because the material is displaced instead of removed, rolled threads are typically hardened and have smooth finishes. Figure 4 illustrates the physical differences between parts that undergo thread cutting and thread rolling.

In CPI applications that require thread accuracy, rolling has significant advantages over thread cutting. Rolled threads have smooth finishes, very tight tolerances, superior strength, resistance to fatigue and consistent thread geometry — all desirable properties of equipment used for chemical processing. Thread accuracy and consistency is critical for any harsh environment. When assembling a product, ensuring consistent flow and preventing leakage results in a more reliable and efficient final product. This will not only improve the safety of personnel, but it will also reduce the loss of expensive chemicals. Consistent surface finishes also prevent harsh chemicals from attaching to imperfections, pits or tool marks on the metal surface.

At this point, a design engineer may ask: how does thread rolling relate to material selection? As mentioned, metals are the most commonly chosen material class for the design of chemical processing equipment. Despite being more corrosion-resistant, stronger and resistant to fracture, metals can also possess qualities that make them difficult to machine. Because the CPI count on many types of metals for safety and reliability, choosing the most suitable machining method for specific materials is important for the design of threaded parts and valves.

Machining solutions

As previously discussed, exotic and hard-to-machine metals, such as stainless steels, titanium and nickel-based alloys like Inconel, are often chosen due to their physical properties' capabilities in the required application. However, these materials also have various undesirable properties that can create challenges. These potential issues can usually be overcome by selecting the correct machining method.

Ease of machining. Ductility, or a material's ability to deform without fracture, is a major property that determines its machinability. Steels and nonferrous metals that are less ductile will typically break and produce chips and impurities as material is removed. As a result, thread cutting is a very ineffective method of machining for these materials. Although these metals do not deform easily and require much greater amounts of pressure to form threads, they typically roll very efficiently and yield the consistent thread geometry and smooth surfaces that are desirable for equipment components used in the CPI. The ductility of a specific material can be acquired from an ASTM International test.

Smooth surfaces. When a material is cut, the microscopic particles that are left behind can cause thread galling. Galling is a form of wear caused by the sliding and friction between two metal surfaces. Unlike some forms of wear that occur over time, the negative effects of galling will be observed as soon as the metal parts are assembled and in sliding contact. When a metal surface galls, microscopic particles break off and foul the operating environment. Galling is most common in ductile metals like aluminum compounds, because particles are more prone to transfer during motion.

Although these ductile metals are more likely to gall, the high pressures of the dies during the thread-rolling process makes the metal surfaces harder and denser. This means that the presence of microscopic particles that typically form during the machining of ductile metals is significantly reduced. Choosing thread rolling is a strategy that a designer can take prior to production that can result in smooth surfaces on various types of metal fasteners and threads.

Protecting against oxidation. As discussed, oxide layers form in many types of metals, such as stainless steel, titanium or aluminum, for increased corrosion protection. However, this can cause significant issues for threads and mated parts.

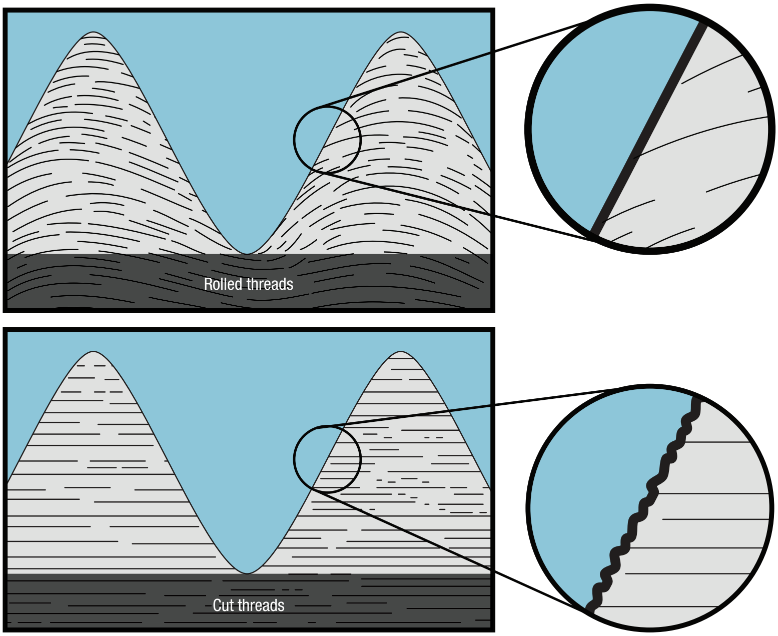


FIGURE 4. Thread cutting and thread rolling are the two most commonly used methods for the machining of threaded parts

If the surfaces of the threads have impurities or imperfections, they will cause increased friction as parts tighten. This causes the oxide films on the surface to be scraped away, leaving behind damage to the underlying layers of metal. These damaged and exposed layers are prime starting points for galling. Typically, surface finishes are used as a preventive measure, but in many chemical-processing applications, such as food or pharmaceutical processing, the selected finish must meet the regulations of the U.S. Department of Agriculture (USDA; Washington, D.C; www.usda.gov) or the U.S. Food and Drug Administration (FDA; Silver Spring, Md.; www.fda.gov) to avoid contamination. In these cases, thread rolling can be a means of eliminating the impurities that can adhere to these surfaces and cause oxide layers to come apart.

Complete material isolation. In CPI applications, the isolation of material is often critical, so valves are used to constrain the flow of gases, liquids or vapors to a specific location. These

FIGURE 5. An understanding of the thread-rolling technique helps engineers to save costs when specifying materials for valve internals

isolation valves require highly reliable shutoff and sealing capabilities in order to prevent dangerous leaks in harsh operating environments. Application-specific materials may prevent corrosion, but rolled threads can help to ensure stronger seals and connections.

Rolled threads are work-hardened without the removal of material, so the natural material grains are left unbroken and continuous. As a result, these threads have much higher yield strengths and tighter tolerances than that of cut threads. The uniform thread geometry of rolled threads allows parts to fit together better, with fewer chances for sliding or loosening. Depending on the ductility of the material, tolerances of rolled threads can be as tight as ±0.015 mm. These tight tolerances are ideal for threaded valve joints and connections that require reliable material isolation and shut-off.

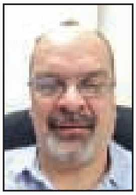
Production costs. As with material selection, the selection of the machining method can impact costs. The thread-rolling process is much more efficient than cutting, and in some cases can result in 90% decreases in production times. Unlike the cutting tools that must be sharpened and reset periodically during machining, the dies used for rolling can continue production for long periods of time. Die lifetime is an important factor in considering machining costs. Figure 5 shows an example of some internal components from a high-pressure fog valve that are constructed of 316 stainless steel. For such components, the designer has the option to specify full thread crest, if required. However, if an application does not require full thread crest, the costs will be lowered because the die life is increased when the crest is not full. This has no impact on the effective portion of the thread. Full thread crest was not specified for the components in Figure 5.

The accuracy of rolled threads is another factor that makes them cost-effective, because the need to frequently inspect threads for consistency during production runs is eliminated. This saves on costs of labor. By rolling threads, the design engineer will observe the exact same thread geometry for the first part as the last.

An understanding of the intended functionality and operating environment is significant in deciding on a material for a small threaded part or valve component in the CPI, but this is only part of the process. Going a step further in the design of these components by specifying the machining method is another way of ensuring that the part will operate at peak performance when manufactured from the desired material. ■

Edited by Mary Page Bailey

Author



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Managing Small and Medium-sized Capital Projects

A real-life example is provided to show how to stay on program and within budget

Peter Hessler
Construction Business Associates, LLC

Construction Business Associates, LLC

FIGURE 1. Can the owner of this chemical plant expansion be assured that this relatively small project will be completed on time and within budget? Yes, and with relative ease, if the team follows the recommendations proposed here

Over the past few years, much has been written in the trade press about how to manage large, $1-billion-plus plant-construction and expansion projects in the chemical process industries (CPI). However, when it comes to managing projects with a smaller scope — say, projects in the $25–250 million range — a variety of nuanced management issues arise. Such projects include small new plants, additions to existing plants, and expansions of currently operating facilities. This article suggests practical and immediate ways to deal with some of the unique management challenges that often arise.

Large mega-projects are usually managed by one of the larger, world-renowned contractor firms, which have a full suite of project-management tools, capabilities and expertise at their disposal. Such contractors have built larger-than-life projects, using tried-and-true project-management protocols that have been successfully used on hundreds of projects over many decades around the world. Although problems do occur, they are more often related to misunderstandings than surprises, and the contractor usually has the deep expertise needed to address any of these problems as they arise.

However, smaller, more frequently incurred projects, such as plant expansions or conversions, are often managed by smaller, less-experienced contractors, who do not always have expertise or experience with the sophisticated project-management processes that are used by the mega-contractors. As a result, such projects often run way over budget, defy timeline constraints, present numerous surprises, and even lead to lawsuits.

One reason is that the CPI plant personnel who are frequently tasked with the responsibility of overseeing such projects are not, by training, project managers. Rather, their expertise lies in running the plant on a day-to-day basis — ensuring that raw materials are available, that existing equipment is ready for production, and that trained personnel are available to make the product. Their expertise does not lie in the realm of managing engineering manhours for plant design, or in procuring and expediting the delivery and deployment of large tanks, reactor vessels, pumps, motors and more. And the experience and expertise required to determine if the construction portion of the project is progressing as promised and as needed to meet budget, schedule, quality and safety norms is typically beyond the skill set of most plant personnel — they are simply not experts at managing a team of contractors.

Nonetheless, many CPI organizations still try to manage the contractors who are building their small or medium-sized new plant or expansion projects by using only their existing plant personnel. Sometimes they derive comfort from assurances from their contractors, who say "nothing will go wrong."

Often this is due to a reluctance to spend extra money on third-party overseers. Sometimes it is due to a perception that since project building and construction management are not based on finely tuned formulas and recipes, these activities can simply be overseen by existing plant personnel, adding just a few hours per week of extra duties to an already full-time schedule.

Unfortunately, as is often the case, the result of such an approach is a scenario characterized by budget overruns, schedule delays, and at times, lawsuits.

A real-life example

Discussed below is a real-life example of what can happen "when the meager are challenged by the eager." At one CPI facility (Figure 1), a plant expansion was undertaken, involving the construction of a new facility to replace an existing one, with the goal of more than doubling the number of products from 80 to 170. The project was planned to be performed with no downtime — so the existing facility continued to produce the initial 80 products throughout this initiative.

Now envision this new facility designed for 14 newly added production vessels and reactors, each requiring its own pumps, motors and valves, and tapping into shared service systems. Imagine more than two dozen extra-large holding tanks, indoors and outdoors, each with its own set of pipes, pumps, motors and valves, all feeding into the 14 production vessels and reactors.

Add to this the need to build a structure to house all of this — just one aspect of the project that required more than 2,500 cubic yards of concrete (enough to build a ten-mile long sidewalk), and more than 600 tons of structural building and support steel. The five miles of stainless steel piping connecting all of these tanks, vessels, and reactors required 15,000 individual butt welds. Also required were power cables — more than 13 miles of them — and nearly 30 miles of instrumentation cables to connect more than 1,500 instruments. Although this project involved only one main contractor, there were 50 subcontractors involved, and each required coordination and support, in a planned period of 14 months.

How does the plant manager, or his or her designee, know when trouble might be just around the corner? Usually, the main contractor promises that nothing major will go wrong, but in the event that there are signs of impending problems, the contractor promises that the management tools and protocols being used will highlight them in plenty of time to allow corrective action to be taken. This was the case in the above-described project.

When reality sets in

At some point, reality does set in, as it did in the case discussed here. One day the plant manager decided his staff was too short-handed to really know where the project stood. There were more than 100 craftsmen on the job, large vessels, tanks and reactors were arriving on a regular basis, pipe prefabrication had begun at an off-site facility, and safety issues were cropping up. The plant staff just could not stay on top of it all. So a third-party overseer was engaged.

That engagement resulted in a series of project reviews and subsequent discussions. The first item that was discussed was the current project status — that is, what was the contractor's perception in terms of the percent of the work complete at that time? At that point, the contractor was reporting that the project was 46% complete.

The first question from the third-party consultant was: "So that means there's only 54% more to go, and then you're done?" The answer was not a resounding yes. The next question sought to learn how the 46% assessment was derived. As it turned out, that estimate had nothing to do with the work effort actually being expended — the primary measurement needed to predict when a capital project will be done, and at what cost.

Therefore the discussions turned to how to better recalibrate progress measurement. The contractor was encouraged to look at the remaining work and decide how it should be scheduled going forward — by individual disciplines (such as civil works, steel erection and piping), or by entire systems (such as reactor vessel systems 1, 2, 3 and so on)? Because if the project really was 46% complete, the work measurement and focus should have been on reactor vessel systems instead of disciplines for quite some time. Everyone agreed on this.

To improve the progress-measurement process, the contractor restructured the schedule to reflect the work that remained in order to complete the original 14 production vessels and reactors and their support equipment. This now allowed the plant manager and staff to visualize where progress was actually occurring, and where it was not.

At the time the contractor professed 46% progress, almost none of the 14 vessels or reactors had yet been placed in the building. Almost no connecting piping had been received onsite. And a check of the warehouse receiving area showed almost no valves, instruments and other sundry items on hand and ready for installation. It was clear that the "46% complete" number was not a realistic reflection of the situation at that time. So then the open question was, what should it have been?

Measuring progress

Since the project would ultimately have more than 5 miles of piping, the contractor suggested the project's progress could be measured in terms of feet of piping installed. This logic was agreed upon, because everything in the plant (outside of electrical work) was ultimately dependent on the piping in one way or another. For example, the steel was needed not only to frame the building in which the piping would reside, but also to support the piping as it was being hung. The piping then would connect all of the 14 production systems, their vessels, tanks, reactors, pumps and motors. Even installation of most of the valves and instruments (not yet onsite) would ultimately be dependent upon the piping. Ditto for the insulation. Therefore tying the project progress to the amount of piping installation completed made sense.

However, that was not the end of the story. The contractor's suggestion that using the number of feet of piping installed as a proxy for the project's progress had an obvious flaw. Since progress measurement, which is tied to schedule and cost, is really about work effort, the manhours required to put piping in place had to be considered. For example, how much effort does it take to raise into place a two-foot section of pipe versus a four-foot section? Essentially the same, except that the four-foot piece could claim twice the progress of the two-foot piece.

So a slightly different measurement was required, and that measurement was the number of pipe connections, in this case welds. Regardless of the length of the pipe, only the number of completed welds truly reflects the real progress of the piping work; hence this measure serves as an even better proxy for the progress

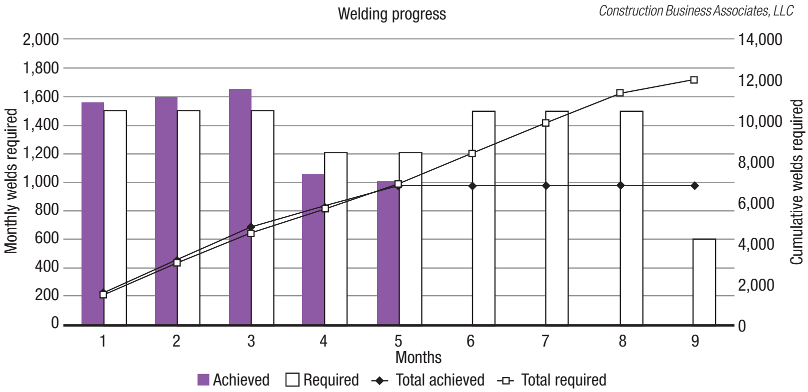

FIGURE 2. Shown here is a snapshot of the remaining 12,000 welds required to complete the project, and the actual pace of completion

of the overall capital project.

Therefore, a system of weld counts was developed. This approach, universally used in the construction of large power plants, was easily applied to this project. Since almost all of the welds were of the same size and wall thickness, a straightforward count of welds sufficed, as opposed to the concept of determining equivalent welds.

The system was simple. Using the design documents, most of the 15,000 welds were assigned to each of the 14 systems and the remainder were attributed to a category called "common." In this manner, as welds were completed, one could now not only determine the project's overall percent complete, but also determine the approximate state of readiness of each of the 14 systems.

For example, let's say that each system had approximately 1,000 welds associated with it. That then left 1,000 welds to be assigned to the common category. So the agreement was that only once 7,500 welds were complete could the project work be called 50% complete, and this was not yet the case.

When the consultant was engaged, a detailed weld count revealed that only 3,000 of the 15,000 welds had been completed — leaving 12,000 welds still to be completed. Figure 2 shows the plan for those remaining 12,000 welds over the next nine months, and the actual progress to the mid-point of the job.

As shown in Figure 2, 50% of the total 15,000 welds were completed in the fifth month of welding. Per the earlier agreement, that then equated to a project completion of 50%.

However, once a construction project, such as this chemical plant expansion, reaches that 50% completion stage, the focus needs to shift to include commissioning and startup. In this case, it was comforting to finally know that after 5 months of welding, approximately half of the work effort was complete — but this did not assure that all 14 systems would be ready for commissioning and startup, as needed, for the upcoming production cycle. So, attention was shifted to determine which of the 14 systems needed to be ready when. The systems were prioritized, and this effort helped to determine exactly which welds had to be made next.

One could now take the position that, having established a rational approach for measuring progress and establishing priorities, the work was well in hand and minimal attention needed to be paid to the remaining efforts of the contractor. Unfortunately, such a position is never prudent, and letting go of the management details could still end up with the project in a state of disaster. For this real-life project, this was fortunately recognized by all parties.

Costs

The question to be asked at this stage of the project was whether or not the contractor could meet the resource requirements to get from the current 50% to 100% within the allotted budget, in accordance with the restructured schedule. To answer this question, an additional view of the project was required — beyond just measuring the percent completed. The added insight required that the percent complete needed to be measured and plotted against time, so that the project could progress going forward. Figure 3 provides an example of this.

As shown in Figure 3, plotting manhours (on the left vertical axis), and percent complete (on the right vertical axis) against time on the horizontal axis, both against a planned percent-complete curve (shown with a black dashed line), tells an interesting story. It shows that after 7 months, the 14-month project is essentially at the 50% point, just as was planned. However, it also shows that the costs are exceeding the budget, and actually have been since the work was initiated. If this were allowed to continue without a change in course, it would have resulted in a 20% overrun (or greater) of the budget.

In most scenarios, this is not acceptable. So the project team needed to review the plans that were in place for completing the second half of this project.The goal was to see if there might be alternate approaches that would still maintain the schedule while also maintaining or reducing the costs and resources required. Usually, at this stage of the project, there are still some opportunities to change the trajectory of the budget projections and timelines. In this particular project, with half of the welding still to be completed, changing from manual to orbital welding provided an ideal opportunity to reduce future costs (by reducing the number of hours required to complete this work).

The outcome

Ultimately, this project was completed on time and within budget. However, it is doubtful that outcome would have been the result without

BUILD TRANSPARENCY

The key to building transparency in a complex expansion or revamp project is to know:

- When to switch from measuring by discipline to measuring by system
- How to determine progress as it relates to work effort
- How to measure progress as it relates to productivity
- How to measure progress as it relates to budget
- How to determine overall project completion

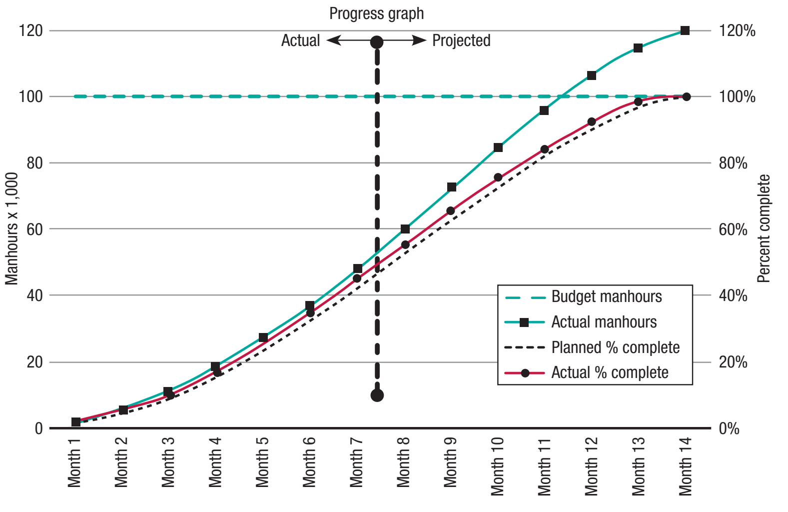

FIGURE 3. This progress graph projects that if no changes are made, the project will still be completed on time, but almost 20% over budget

the intervention of someone attuned to the intricacies of project management, someone who understood the complexities of linking the worlds of engineering and equipment procurement with the world of construction (classically called EPC management). The intervention started with a shift to manage the project not by physical disciplines, such as civil, steel and mechanical erection (the traditional approach), but by production systems (discussed earlier). This allowed everyone's focus to be realigned to concentrate on, and prepare for, the systems' readiness.

The next step was to develop a system of progress measurement that reflected actual work effort expended versus the effort that was still required. In other words, if a project is 46% complete, does that truly translate into only 54% more work effort manhours required to complete the project? The challenge here is to pick a measurement that is readily understood, yet representative of both the actual work performed and the remaining work still to be performed. In this case, settling on the measurement of the number of piping welds completed was key.

The third step was to marry the progress measurement and percent-complete with the work effort expended. In reality, the goal was to determine the work effort still required to get to completion (that is, how many manhours have been used versus how many more are required to complete the work). Comparing these two metrics (percent complete and manhours still to be expended) against a timeline provides insight into whether the project will be completed on time and within budget. In this case, the answer was no, unless other, less costly or more-efficient ways were found to complete the remainder of the work. This challenge was addressed by switching to orbital welding.

The rest of the story

The prior discussion concentrated on the mechanical work required to complete this project. Similar approaches were taken with the electrical work and the instrumentation wiring. These disciplines, within each of the 14 systems, were also measured and compared to percent complete against time.

For the electrical work, wiring terminations were used in a similar manner as weld counts (as a reasonable proxy for work completed). The mechanical work then was prorated with the electrical and instrumentation (E&I) work to derive a total percent of the project completed. For this project, the mechanical work was assigned a value of 65% (based on total manhour requirements). The E&I work was collectively assigned a 35% value. So when half of the mechanical work was complete (50%), and the 20% of the E&I work was complete, the overall project was 40% complete, calculated as follows:

Mechanical work = 65% of the project
x 50% complete
= 33% of the total project completed

E&I work = 35% of the project
x 20% complete
= 7% of the total project completed

Adding these two numbers (33% plus 7%) demonstrates that 40% of the total work had been completed. This measurement process continued until the project reached completion (100%).

The takeaway

In summary, when faced with an EPC plant build-out or expansion project that does not involve a large, dedicated industrial plant construction contractor, thought should be given to what could go wrong. Does the plant staff have the project management experience to ensure total transparency between the contractor and the plant? Even if it does, will the plant management staff have the time required to ensure this? Is there someone available who can provide the proverbial "sniff test" that all aspects are on track? In other words, is someone available on staff to drill down into the details of the project to ensure this transparency?

If the answer to all of these questions is a definite yes, then no more is required. However, if it is not an unqualified yes, then the project would benefit from a third-party partner to provide support and oversight. ■

Edited by Suzanne Shelley

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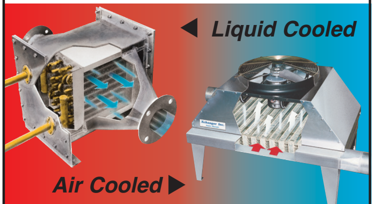

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2	17	32	47	62	77	92	107	122	137	152	167	182	197	212	227	242	257	272	287	302	317	332	347	362	377	392	407	422	437	452	467	482	497	512	527	542	557	572	587
3	18	33	48	63	78	93	108	123	138	153	168	183	198	213	228	243	258	273	288	303	318	333	348	363	378	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
11	26	41	56	71	86	101	116	131	146	161	176	191	206	221	236	251	266	281	296	311	326	341	356	371	386	401	416	431	446	461	476	491	506	521	536	551	566	581	596
12	27	42	57	72	87	102	117	132	147	162	177	192	207	222	237	252	267	282	297	312	327	342	357	372	387	402	417	432	447	462	477	492	507	522	537	552	567	582	597
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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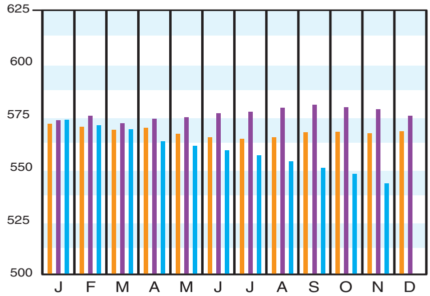
2013 ▬ 2014 ▬ 2015 ▬

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

CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957-59 = 100)	Nov. '15 Prelim.	Oct. '15 Final	Nov.'14 Final
CE Index	543.0	547.2	578.4
Equipment	648.9	654.9	702.5
Heat exchangers & tanks	566.6	575.4	649.3
Process machinery	652.3	655.0	662.9
Pipe, valves & fittings	803.4	808.6	875.4
Process instruments	386.6	390.1	411.7
Pumps & compressors	956.5	956.4	942.9
Electrical equipment	508.4	508.2	516.2
Structural supports & misc	713.4	723.6	769.9
Construction labor	324.3	325.8	322.4
Buildings	539.3	540.4	546.9
Engineering & supervision	318.2	317.7	320.1

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

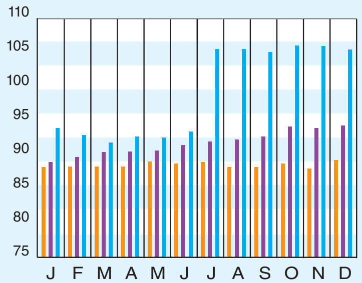


Starting with the April 2007 Final numbers, several of the data series for labor and compressors have been converted to accommodate series IDs that were discontinued by the U.S. Bureau of Labor Statistics

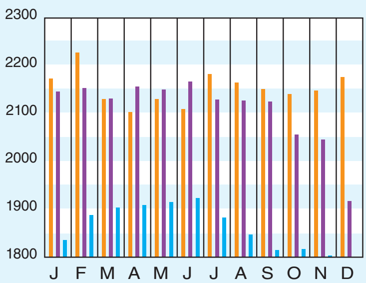
CURRENT BUSINESS INDICATORS

CURRENT BUSINESS INDICATORS	LATEST			PREVIOUS						YEAR AGO		
CPI output index (2012 = 100)	Dec. '15	=	105.4	Nov. '15	=	106.0	Oct. '15	=	105.9	Dec. '14	=	105.3
CPI value of output, $ billions	Nov. '15	=	1,803.7	Oct. '15	=	1,813.3	Sept. '15	=	1,818.9	Nov. '14	=	2,069.4
CPI operating rate, %	Dec. '15	=	75.8	Nov. '15	=	76.3	Oct. '15	=	76.4	Dec. '14	=	76.6
Producer prices, industrial chemicals (1982 = 100)	Dec. '15	=	233.4	Nov. '15	=	234.6	Oct. '15	=	237.3	Dec. '14	=	263.4
Industrial Production in Manufacturing (2012=100)*	Dec. '15	=	106.0	Nov. '15	=	106.1	Oct. '15	=	106.2	Dec. '14	=	105.2
Hourly earnings index, chemical & allied products (1992 = 100)	Dec. '15	=	159.4	Nov. '15	=	160.4	Oct. '15	=	159.3	Dec. '14	=	157.3
Productivity index, chemicals & allied products (1992 = 100)	Dec. '15	=	107.5	Nov. '15	=	107.0	Oct. '15	=	105.8	Dec. '14	=	106.1

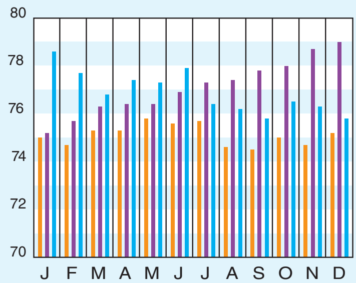
CPI OUTPUT INDEX (2000 = 100)†



CPI OUTPUT VALUE ($ BILLIONS)



CPI OPERATING RATE (%)



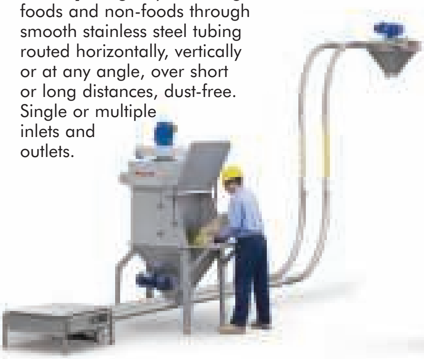
*Due to discontinuance, the Index of Industrial Activity has been replaced by the Industrial Production in Manufacturing index from the U.S. Federal Reserve Board.
†For the current month's CPI output index values, the base year was changed from 2000 to 2012
Current business indicators provided by Global Insight, Inc., Lexington, Mass.

CURRENT TRENDS

The preliminary value for the November 2015 *CE* Plant Cost Index (CEPCI; top; the most recent available) declined again from the previous month, driven by a relatively large decrease in the Equipment subindex and small decreases in the Buildings and Construction Labor subindices. The Engineering and Supervision subindex saw a small increase in November. The preliminary CEPCI value for November 2015 is 6.1% lower than the corresponding value from a year ago at the same time. Meanwhile, the latest Current Business Indicators (CBI; middle) numbers showed a decline in the CPI output index, as well as in the CPI value of output index and in producer prices for industrial chemicals. The productivity index was up slightly.

CONVEY

FLEXI-DISC® Tubular Cable Conveyors gently slide fragile foods and non-foods through smooth stainless steel tubing routed horizontally, vertically or at any angle, over short or long distances, dust-free. Single or multiple inlets and outlets.



DUMP

FLEXICON® Manual Dumping Stations allow dust-free dumping of bulk material from bags and other containers. Automatic reverse-pulse filter cleaning allows continuous, efficient operation. Available with integral bag compactors for total dust containment.

UNLOAD

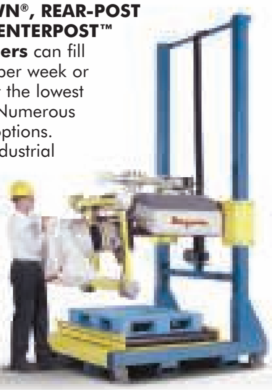
BULK-OUT® Bulk Bag Dischargers unload free- and non-free-flowing solids from bulk bags automatically. Allows untying, discharging, retying and collapsing of bulk bags—all dust-free. Available with weigh batching controls.

CONDITION

BLOCK-BUSTER® Bulk Bag Conditioners loosen bulk materials that have solidified during storage and shipment. Variable height turntable positions bag for hydraulic rams with contoured conditioning plates to press bag on all sides at all heights.

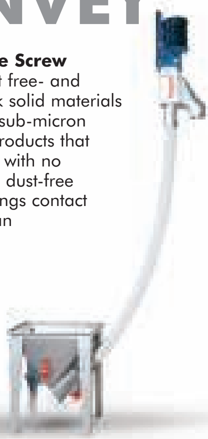
FILL

SWING-DOWN®, REAR-POST and TWIN-CENTERPOST™ Bulk Bag Fillers can fill one bulk bag per week or 20 per hour at the lowest cost per bag. Numerous performance options. Available to industrial or sanitary standards.



CONVEY

FLEXICON® Flexible Screw Conveyors transport free- and non-free-flowing bulk solid materials from large pellets to sub-micron powders, including products that pack, cake or smear, with no separation of blends, dust-free at low cost. No bearings contact material. Easy to clean quickly, thoroughly.



CONVEY

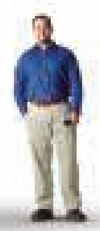
PNEUMATI-CON® Pneumatic Conveying Systems move a broad range of bulk materials over short or long distances, between single or multiple inlet and discharge points in low to high capacities. Available as dilute-phase vacuum or positive pressure systems, fully integrated with your process.

DUMP

TIP-TITE® Container Dumpers dump bulk material from drums (shown), boxes or other containers into vessels up to 10 ft (3m) high. Dust-tight (shown) or open chute models improve efficiency and safety of an age-old task.

SUCCEED

The FLEXICON® Lifetime Performance Guarantee* assures you of a successful result, whether you purchase one piece of equipment or an engineered, automated plant-wide system. From initial testing in large-scale laboratories, to single-source project management, to after-sale support by a worldwide network of factory experts, you can trust your process—and your reputation—to Flexicon.



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