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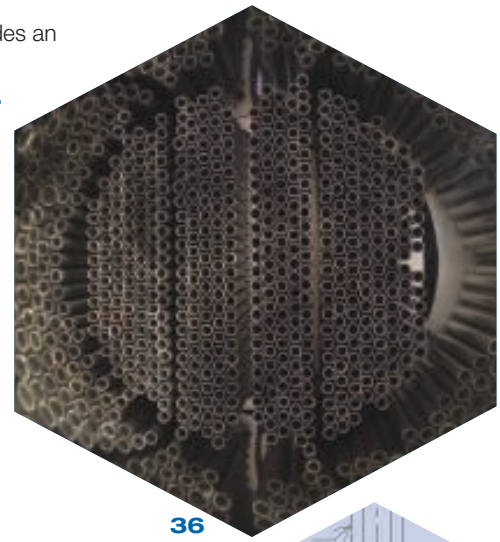

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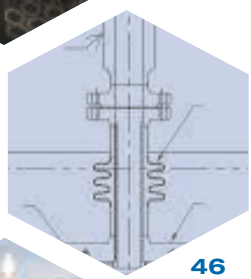

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Cover photo: The photo shows a fuel pool cooler being fabricated for the Exelon Peach Bottom Nuclear Power Plant; photo courtesy of American Exchanger Services Inc.

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BPA

Editor's Page

The rising role of alternative energy

The news making recent headlines in my local area is the announcement of the closing of the Indian Point nuclear power plant in New York State. Whether to keep the plant running or not has been a long-debated issue, with strong arguments on both sides. In January, New York Governor Cuomo announced that the plant will close by April 2021. Along with accolades from environmental groups and local residents concerned about safety and security, are concerns about what the plant closing means economically and how to replace the 2,000 MW of electricity that the plant supplies to the area, which includes New York City.

The plan to replace power from the plant includes alternative energy sources, such as hydroelectric power, as well as upgrades and efficiency measures. In line with last year's approval of New York's Clean Energy Standard — which sets a goal to have 50% of New York's electricity come from renewable sources by 2030 — there is also a proposal for an offshore wind project, 30 miles from the tip of Long Island.

Solar power shines

More and more, alternative energy options are making their mark as emerging power sources. Solar power is becoming the cheapest form of new electricity, according to a recent report by Bloomberg New Energy Finance[1]. The report indicates that solar prices are competing with those of coal and natural gas, and that solar prices are even falling below those for wind power in some countries. A recent memo by the U.S. Dept. of Energy (DOE)[2] says that in the U.S., the cost of large scale (>100 MW) solar photovoltaic has dropped by 64% since 2008, and that the number of such plants has grown from 0 to 50 in the U.S. during that time.

Technological advances made by those working in the chemical process industries (CPI) are undoubtedly contributing greatly to alternative energy's progress. In addition to technological developments to solar panels, which are familiar to many of us through their common usage in consumer products, other areas are seeing increasing progress. See the article in this issue on "Concentrating Solar Thermal Power: The Future Looks Bright" on pp. 15–18 for more on solar power.

Energy efficiency and process intensification

In addition to developing technologies for energy resources, the CPI play an important role in reducing energy needs by providing products for energy efficiency. The CPI themselves consist of many energy-intensive operations, and they are also working on improving efficiency in their own processes.

Process intensification is an effort to improve energy efficiency, reduce resource use and increase overall manufacturing productivity. Recently, the DOE announced that the Rapid Advancement in Process Intensification Deployment (RAPID) Manufacturing Institute was selected to join the nation's network of Manufacturing USA Institutes The institute was formed by the American Institute of Chemical Engineers (AIChE) and will leverage federal funds, as well as funds from the participating members, toward its goal of increasing energy efficiency and productivity by 20% in 5 years.

The ambitious goals for energy efficiency and alternative sources offer great opportunities for chemical engineers and others in the CPI to contribute. ■

Dorothy Lozowski, Editor in Chief

1. www.bloomberg.com/news/articles/2016-12-15/world-energy-hits-a-turning-point-solar-that-s-cheaper-than-wind
2. energy.gov/sites/prod/files/2017/01/f34/Department%20of%20Energy%20Cabinet%20Exit%20Memo.pdf

Letters

Pump Safety: Flirting With Disaster

I just finished reading your article (Pump Safety: Flirting With Disaster, pp. 67–70, December 2016) and want to indicate the following:

In the third example, the text said that the H_{BEP}/H_{SO} is 0.7, but in the formula, 0.75, (0.75–1) is written as the divisor. With 0.7, the relation Q_{SO}/Q_{BEP} is 0.166666, which is less than the stated 0.20.

By the way, I found the article very interesting.

Ernesto Calderón
Head of Design Process Engineering, Techint

Author's response

Mr. Calderón is correct. He must have read the article very carefully to glean that, in Example 3, I stated that H_{BEP}/H_{SO} was 0.7, but inserted a value of 0.75 into the calculation. With the correct value (0.7), you get a Q_{SO}/Q_{BEP} ratio of 0.166666, which is lower than the value of 0.20 that I stated.

We need to thank Mr. Calderon for identifying the error in my calculations and then calculating the correct value for the Q_{SO}/Q_{BEP} ratio.

Robert Perez

Editor's note: The correction to Example 3 as stated above has been included in the online version of this article: www.chemengonline.com/pump-safety-flirting-disaster

Re-Establishing Course

Your article in the November 2016 edition of *Chemical Engineering* was excellent (Re-Establishing Course, pp 67–70; www.chemengonline.com/re-establishing-course). There is so much pertinent information, very to the point and written from your [the authors] personal experience — not by some person just "imagining" what the situation of having to re-establish course would be like. There is nothing like first-hand knowledge to give weight to a story.

I am retired and not in a position of looking for employment, although I have had a few part- and full-time jobs that needed my area of expertise. I read the story because it sounded interesting and the further I got, the more it made an impression on me. If I were in a position of needed to "start over," I would have your story as my main guide. Thank you very much.

Brian T. Bender
Napa, California

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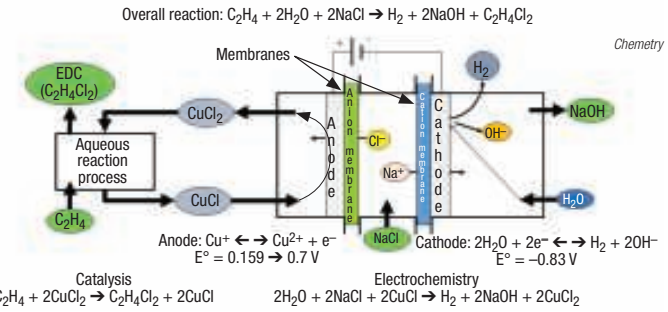
- Comments about today's engineering practice or education?
- Job-related problems or gripes to share?

If so — Send them, for our Letters column, to Dorothy Lozowski, Editor in Chief, *Chemical Engineering*, dlozowski@accessintel.com

A new low-energy electrolytic path to ethylene dichloride

New process technology from Chemetry (Moss Landing, Calif.; www.chemetry corp.com) aims to revitalize the chlor-alkali product chain by manufacturing ethylene dichloride (EDC) and caustic using much less power than conventional processes. Through an exclusive licensing and engineering agreement, Technip (Paris, France; www.technip.com) is helping to commercialize Chemetry's eShuttle technology. The company has operated a continuous pilot plant since 2014, and is now scouting operating partner sites to construct a full-size demonstration plant.



Combining a specialized three-compartment electrochemical cell and an aqueous catalysis step, eShuttle uses the same raw materials as typical chlor-alkali processes while eliminating the chlorine gas intermediate. In addition to saving power, removing chlorine makes the process inherently safer and allows for longer membrane life and simpler startup and shutdown, as no chlorine purge or disposal is required. Furthermore, since no chlorine gas is present in the system, eShuttle's electrochemical cell is much thinner than those used in traditional chlor-alkali processes, which can provide for increased production rates within the same footprint, explains Chemetry CEO Ryan Gilliam. This makes eShuttle very attractive in the retrofit market.

In the eShuttle process, copper chloride is used as a carrier for chloride ions. The copper chloride is oxidized as it picks up chloride ions and flows in a closed loop between the electrochemical cell's anode and the reaction step (diagram). "Using this copper-chloride shuttle reaction allowed us to fundamentally lower the energy," says Gilliam, because the voltage required for copper oxidation is much lower than that of the chlorine evolution reaction that takes place within traditional chlor-alkali systems. This difference amounts to a 30% reduction in power per ton of caustic, says Gilliam. The power consumption can be further reduced by as much as 53% through integration of oxygen depolarized cathode (ODC) technology, with which eShuttle is compatible.

Extending biomass catalyst life by removing minerals

Anellotech Inc.'s (Pearl River, N.Y.; www.anellotech.com) biomass-to-aromatics (Bio-TCat) process pyrolyzes woody biomass and converts the pyrolysis gases to aromatic hydrocarbons using zeolite catalysts in one reactor (see *Chem. Eng.*, March 2016, p. 7). Pyrolysis is the rapid decomposition of organic material at high temperatures in the absence of oxygen.

Anellotech has used forest products as feedstocks for its pyrolysis process in part because of their low mineral content. Minerals present in biomass can deactivate zeolite catalysts, reducing catalyst lifetimes. Now, Anellotech has developed a low-cost pretreatment technology that removes minerals from biomass, significantly extending catalyst lifetimes when processing wood, and greatly expanding the range of biomass raw materials that can be used for its aromatics process.

The patent-pending process, known as MinFree, "allows us to use a broad range of non-food biomass, including inexpensive agricultural residues like corn stover or sugarcane bagasse, that have higher mineral contents," explains David Sudolsky, CEO of Anellotech.

The company and its partners have successfully produced ton quantities of biomass using the MinFree process, and will be using MinFree-processed biomass at its TCat-8 seven-story development and testing unit, which is located at South Hampton Resources' chemical manufacturing facility in Silsbee, Texas. Commissioning of Anellotech's development unit began in October 2016, and Sudolsky says the commissioning phase is targeted to be completed in the first quarter of 2017.

Edited by:
Gerald Ondrey

CYCLOHEXASILANE

3DIcon Corp. (Tulsa, Okla.; www.3dicon.net) has signed a supply agreement with Gelest Inc. (Morrisville, Pa.; www.gelest.com) to produce cyclohexasilane (CHS) at pilot scale using 3DIcon's newly developed CHS process. 3DIcon's process (see *CE*, Sept. 2016, p. 9) offers a safer and less expensive route to CHS, which can be used to make a number of important silicon-based products. Under the agreement, Gelest will manufacture CHS for use by 3DIcon's potential commercial partners, and to support federal business-development grants being pursued by 3DIcon. Also, Gelest and 3DIcon will work to optimize the novel CHS process. Energy storage, solar power generation, microelectronics, printable electronics and solid-state lighting are potential markets for CHS.

FCC CATALYST

As sulfur regulations tighten, petroleum refiners find it increasingly difficult to meet specifications from their fluid catalytic cracking (FCC) gasoline post-treatment units; particularly, the octane number suffers because of the necessary sulfur removal. Late last year, Haldor Topsøe A/S's (Lyngby, Denmark; www.topsoe.com) introduced three new HyOctane catalysts that are specifically developed to solve this problem.

"The three brand new HyOctane catalysts include solutions for all steps in the process and squeeze more value out of any FCC gasoline post-treatment unit," says product manager Claus Brostrøm Nielsen. "Independent testing has shown that HyOctane delivers high HDS (hydrodesulfurization) activity and low octane losses that can compete with any other catalyst on the mar-

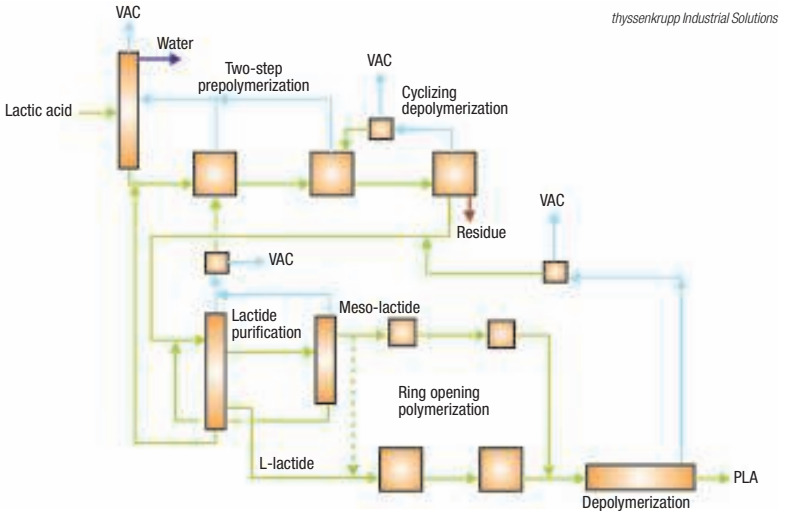
(Continues on p. 10)

Commercial debut for a new PLA-production process

To reduce dependency on petroleum-based plastics, thyssenkrupp Industrial Solutions AG (Essen, Germany; www.thyssenkrupp-industrial-solutions.com) has developed a new manufacturing process for producing the biopolymer polylactide (PLA). The company is now building the first commercial plant based on its patented PLA*neo* technology in Changchun, China, for COFCO Corp. (Beijing, China; www.cofcoagri.com). The new plant will produce around 10,000 metric tons per year (m.t./yr) of PLA, and is scheduled for commissioning in the first quarter of 2018.

In the PLA*neo* process (flowsheet), lactic acid (LA) is first concentrated to remove residual water. The monomer lactide is then purified by a patented distillation technology, using dividing-wall columns. The subsequent ring-opening polymerization takes place using a combination of a continuous stirred-tank reactor (CSTR) and an efficient plug-flow reactor. Before pelletizing, the polymer melt is stabilized and the remaining lactide removed. A very low residual monomer content is achieved due to Uhde Inventa-Fischer's (UIF; a subsidiary of thyssenkrupp; Berlin) proprietary PLA stabilization technology, combined with UIF'S unique one-step demonomerization technology.

Because feedstock costs have a large impact on production costs, the efficient conversion is an important factor, explains Udo Mühlbauer, product manager PLA at UIF. With PLA*neo*, the conversion of LA to PLA is close to the theoretical maximum, thanks to the purification and polymerization techniques for handling the side product meso-lactide, says Mühlbauer. Normally meso-lactide has to be separated and hydrolyzed back to LA, thus reducing the overall efficiency and increasing the feedstock-conversion costs. In the PLA*neo* process, meso-lactide is polymerized and blended with standard, crystalline PLA, without affecting the properties of the PLA product, he says.



UIF first developed the PLA*neo* process in a miniplant in Berlin in 2005, and in 2011 subsequently started up a 500-m.t./yr pilot plant in Guben, Germany. Data gathered from the pilot plant enables UIF to license its PLA process for industrial plants with capacities up to 100,000 m.t./yr.

Because the first commercial plant in China will use lactide (the cyclic dimer of LA) as raw material, only the ring-opening part of PLA*neo* — with the CSTR, plug-flow reactor and demonomerization unit — will be built, says Mühlbauer. However, PLA*neo* can also be fully integrated with the LA process developed by thyssenkrupp Industrial Solutions (*Chem. Eng.*, July 2009, p. 13), whereby LA is produced by the fermentation of glucose or sucrose.

Anisotropic MOFs may open new application doors

Porous crystals called metal-organic frameworks (MOFs) have an extremely large surface area, as well as a large number of pores situated in an extremely small space that offer room for "guest" molecules. Such characteristics make MOFs potentially useful for gas storage or as molecular sieves for the separation of chemicals.

Normally, MOFs will grow with random orientation and position. Now a multinational team has succeeded in growing MOFs with an unprecedented controlled orientation and alignment of the crystals, opening up the possibility of many new applications for MOFs. Controlling the growth creates new properties for the MOFs that can be explored for use in microelectronics, optics, sensors and biotechnology.

The team is led by professor Paolo Falcaro of the University of Adelaide (Adelaide, Australia; www.adelaide.edu.au) and the Technical University of Graz (Austria; www.tugraz.at) and professor Masahide Takahashi of Osaka Prefecture University (Sakai, Japan; www.osakafu-u.ac.jp), with participants from the University of Adelaide, Monash University (Melbourne, Australia; www.monash.edu), the Australian CSIRO (www.csiro.au) and Osaka Prefecture University.

Various substances can be infiltrated into the pores of the crystals to generate anisotropic materials, that is, materials with directionally dependent properties. The same material can show different properties through different orientations and alignments. The team showed, for example, how the controlled synthesis of an MOF film acts in the presence of fluorescent dye. Just by rotating the film, the fluorescent signal is turned on or off, creating an optically active switch.

The team is now developing MOFs for biotechnological applications. It is trying to encapsulate enzymes, proteins and even DNA in MOFs and to immunize their activity against fluctuations in temperature. The crystalline structure surrounding the substance in the pore has a protective effect, like a tough jacket.

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ket today," he says.

The high activity allows for cycle lengths up to six months longer because the catalysts deliver superior sulfur removal at lower temperatures. Alternatively, refiners can utilize the high activity to increase throughput or process feed stocks containing more sulfur, says the company. The optimized activity and selectivity of the new catalysts have been proven in independent testing and also in real-life production.

CO_2 CAPTURE

Last month, the Norwegian University of Science and Technology (NTNU; Trondheim; www.ntnu.no), through its commercialization arm NTNU Technology Transfer, entered into an exclusive license agreement with Air Products (Lehigh Valley, Pa.; www.airproducts.com). The agreement allows Air Products the rights to use NTNU's proprietary fixed-site-carrier (FSC) membrane technology in conjunction with Air Products' proprietary PRISM membrane technology for carbon dioxide capture applications.

Developed over a number of years, the FSC membrane allows for a highly energy-efficient way of capturing CO_2 from fluegas and biogas to produce a high-quality CO_2 offgas (for more details, see *CE.*; November 2007, p. 13). Air Products and NTNU foresee great potential for the application of this technology in areas such as coal-fired power plants and the cement industry, as well as other combustion processes.

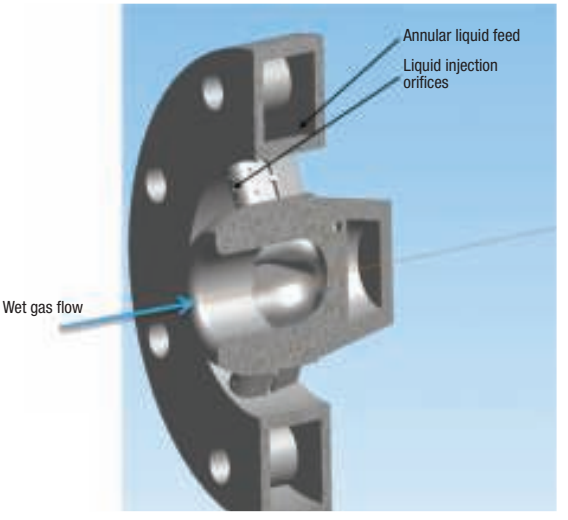
RECYCLING SALT

Many industrial processes produce substantial amounts of wastewater with very high salt concentrations. This wastewater represents a serious pollutant if it finds its way into bodies of water, particularly rivers and lakes used for potable water treatment. To recycle the salt from such industrial waste streams, Covestro AG (Leverkusen, Germany; www.covestro.com) is now coordinating a research project — with partners

(Continues on p. 11)

A more efficient way to dehydrate natural gas — inline

ExxonMobil



A patented, inline absorption system has been developed and field-tested by ExxonMobil (Houston; www.exxonmobil.com), and has just been licensed to Sulzer Chemtech (Winterthur, Switzerland; www.sulzer.com). Because the trade-named cMIST technology operates inside pipes, it replaces the need for conventional methods used to dehydrate natural gas, which takes place in towers. As a result, cMIST reduces the size, weight and cost of dehydration, resulting in reductions of surface footprints by 70% and the overall dehydration system's weight by half, which has significant added benefits for offshore applications, says ExxonMobil. This inline technology could be deployed at both land-based and offshore natural-gas production operations.

ExxonMobil's cMIST technology relies on a proprietary droplet generator to break up conventional glycol solvent into tiny droplets that become well dispersed in the gas flow, thereby increasing the surface area for the absorption of water from the gas. This is followed by an inline separator that coalesces the water-rich glycol droplets and moves them to the outside wall of the pipe for effective separation from the dehydrated natural gas. The water-rich glycol is regenerated using a conventional system and is sent back to the droplet generator to be used again. The droplet generator uses the energy from the flowing natural gas to create droplets of the right size.

This surface technology allows viscous fluids to slide easily

A coating technology that creates a permanently slippery surface that allows even sticky, viscous fluids to flow easily without leaving residue has been newly applied industrially.

Developed at the Massachusetts Institute of Technology (MIT; Cambridge, Mass.; www.mit.edu) and licensed to startup company LiquiGlide Inc. (Cambridge, Mass.; liquiglide.com), the technology consists of a highly textured solid surface combined with a liquid that impregnates the solid material and maintains a permanently wet character. When coated onto process equipment or tanks, the LiquiGlide technology can reduce yield losses and improve cleanability (less downtime and less wastewater from cleaning).

"The textured solid surface acts like a very thin sponge, attracting the liquid via capillary forces, and keeping it place," explains Dave Smith, LiquiGlide co-founder and CEO, so that viscous materials, such as bitumen, cosmetics, food products and others, will not stick to equipment surfaces.

LiquiGlide is not a single coating, but rather a technology platform that uses a proprietary algorithm — based on thermodynamics and fluid mechanics — to select a customized combination of materials for a given substrate material and fluid. For example, Smith says, if the LiquiGlide technology was to be used for a food application, the coating would be made from materials related to the food product and approved for food contact.

Smith notes that a property that differentiates LiquiGlide from other nanotextured surfaces is its ability to self-heal when abrasions occur. "This makes it more durable and longer-lasting than other superhydrophobic surfaces," Smith says.

The technology is commercially available, and the company is working with customers to customize coatings for industrial applications, such as storage tanks, now. The technology is also being targeted at consumer packaging, medical equipment and other areas where viscous materials need to flow, the company says.

New excipient enhances drug solubility

A newly launched pharmaceutical excipient (inactive ingredient providing a vehicle for delivery of oral dosage) enhances the solubility of active pharmaceutical ingredients (APIs) that have poor bioavailability. Tradenamed Parteck MXP, the excipient is a polyvinyl alcohol-based material developed by MilliporeSigma (Billerica, Mass.; www.emdmillipore.com).

Hot-melt extrusion (HME) is a pharmaceutical process intended to increase solubility and bioavailability of APIs when combining them with excipients. "HME increases API solubility by breaking down the crystalline structure of APIs into a more amorphous state," explains Andrew Bulpin head of process solutions strategic marketing and innovation at MilliporeSigma. "The Parteck MXP excipient works to 'fix' this amorphous state into a solid solution form." Increases in solubility can potentially increase the overall bioavailability of the API, Bulpin says.

Traditionally, excipients used in HME can have limitations in the amount of API load, resulting in instability of the amorphous state, and in some cases, are unstable themselves under the high temperatures used in HME. The Parteck MXP excipient, due to its intrinsic properties, can maintain stability (stable above 200°C, the company says) and load more API by weight than with traditional excipients. The company says Parteck MXP allows up to 30% drug load, compared to 10–15% with existing excipients.

The polymer used in Parteck MXP is listed by the U.S. FDA as a GRAS (generally recognized as safe) substance, according to MilliporeSigma. It has been tested on eight common low-solubility drugs so far.

from industry and academia — to develop a process to use the treated salt and purified wastewater in electrolysis processes to produce chlorine.

"A key objective of this project is to increase the salt content of the salt solutions as much as possible in an environmentally friendly manner during the treatment process," says project coordinator Yuliya Schiesser, a process researcher at Covestro. This will be done in part using the waste heat from the adjacent production plants. Covestro is planning a demonstration plant for testing purposes at its Krefeld-Uerdingen site in Germany. In early 2016, the company brought a pilot plant on stream there that uses a recycling process developed in-house to purify salt-laden process wastewater so that it can be reused for the production of chlorine.

PHOTOCATALYSTS

Efforts to develop artificial photosynthesis as a means for making H_2 have been hindered by the degredation of the photocatalysts commonly used in anodes, which have a lifetime of around 20 h. Now, researchers from Japan have developed a water-splitting photocatalyst sheet with a self-regenerating co-catalyst that enhances the durability of oxygen-evolution to longer than 1,100 h. The achievement is a milestone for a project of the New Energy and Industrial Technology Development Organization (NEDO; Kawasaki City, Japan), with researchers from the University of Tokyo, Tokyo University of Science and Japan Technological Research Association of Artificial Photosynthetic Chemical Process. The NEDO team showed that anodes made with Mo-doped $BiVO_4$ particles embedded into sheets possess a stability that is comparable to that of solar cells.

An enzymatic route to lignin-based functional chemicals

Phenpropanone monomers can be produced from lignin via an enzymatic process developed by Yukari Ohta and coworkers at the R&D Center for Marine Biosciences, Japan Agency for Marine-Earth Science and Technology (Yokosuka City; www.jamstec.go.jp), in collaboration with National Defense Academy, Kyoto University and Saitama Institute of Technology. The monomers are produced from wood lignin using multiple enzymes that are derived from a marine bacterial strain. Such monomers have potential applications for making pharmaceuticals, functional foods and cosmetics.

The aromatic monomers are directly made from natural lignin via a cascade reaction of β-O-4-cleaving bacterial enzymes in a one-pot synthesis. Guaiacylhydroxylpropanone (GHP) and the GHP/syringylhydroxylpropanone (SHP) mixture are exclusive monomers from lignin isolated from softwood (*Cryptomeria japonica*) and hardwood (*Eucalyptus globulus*). To demonstrate the applicability of GHP as a platform chemical for bio-based chemicals, the researchers chemically generated value-added GHP derivatives for biopolymers.

Improving the efficiency of solar desalination

Researchers from Nanjing University (Nanjing, China; www.nju.edu.cn) have reported a solar desalination device that is claimed to be much more efficient than existing devices. While typical solar-powered desalinators are not very efficient — only about 30 to 45% of the energy they take from sunlight results in water vapor generation — the new device has an efficiency of 80%.

The conventional design of direct absorber bulk water contact has intrinsic thermal loss through bulk water. The new device's high efficiency is made possible by a confined, two-dimensional water path. Also, due to minimized heat loss, the high efficiency of solar desalination is independent of the water quantity and can be maintained without thermal insulation of the container.

A foldable graphene oxide film, fabricated by a scalable process, serves as efficient solar absorber, vapor channel and thermal insulator. The graphene oxide film is not in direct contact with bulk water, but is physically separated by a thermal insulator (polystyrene foam) to suppress parasitic heat loss. A 2-D water path is enabled by a thin layer of cellulose wrapped over the surface of the thermal insulator. The entire structure can float on the water surface, with only the bottom side of the cellulose in direct contact with bulk water, so an efficient water supply to the absorber on the top surface is enabled by a 2-D surface water path within the cellulose pumped by capillary force. ■

Business News

Plant Watch

Arkema plans $90-million upgrade at Clear Lake acrylic acid plant

January 11, 2017 — Arkema (Colombes, France; www.arkema.com) is investing $90 million at its Clear Lake, Tex. site to replace two acrylic-acid reactors, each with a capacity of 45,000 metric tons per year (m.t./yr), with a single 90,000-m.t./year reactor. The new unit is expected to come onstream in 2019. With completion of this project, Clear Lake's total acrylic acid production capacity will be 270,000 m.t./yr.

Petronas selects LyondellBasell technology for Malaysia HDPE project

January 11, 2017 — A subsidiary of Petronas Chemicals Group Bhd (Kuala Lumpur, Malaysia; www.petronaschemicals.com.my) selected LyondellBasell's (Rotterdam, the Netherlands; www.lyondellbasell.com) process technology to be used for a 400,000-m.t./yr high-density polyethylene (HDPE) unit. The new unit will be constructed at Petronas' Refinery and Petrochemical Integrated Development (RAPID) complex in Pengerang, Johor, Malaysia.

AkzoNobel expands peroxides production in Mexico

January 11, 2017 — Akzo Nobel N.V. (Amsterdam, the Netherlands; www.akzonobel.com) completed a €22-million expansion of its Los Reyes organic peroxides production facility in Mexico. The new facility will produce Laurox brand organic peroxides, which are used in the production of plastics and rubber products.

Fluor wins EPC contract for petroleum refinery in Chile

January 4, 2017 — Fluor Corp. (Irving, Tex.; www.fluor.com) was awarded a contract for the engineering, procurement and construction (EPC) of a new process unit at Empresa Nacional del Petróleo's Biobío refinery in Chile. Fluor will perform the EPC services to install a new fluegas steam generator, a wet-gas scrubber and a purge-treatment unit to treat residual gas generated in the refinery's fluid catalytic cracker to reduce air emissions.

Technip awarded service contract for Socar petrochemicals facilities

January 4, 2017 — Technip (Paris, France; www.technip.com) has been awarded a service contract by the State Oil Company of Azerbaijan Republic (SOCAR) for the engineering design of a new gas-processing plant with a capacity of 10 billion m^3/yr and a new petrochemical plant, which include a steam cracker with a capacity of 610,000 m.t./yr of ethylene and 120,000 m.t./yr of propylene. Technip's work is scheduled to be completed in late 2017.

Linde starts up six ASUs at coal-to-liquids complex in China

January 3, 2017 — The Linde Group (Munich, Germany; www.linde.com) has brought six air-separation units (ASUs) onstream for Shenhua Ningxia Coal Industry Group Co. in Northwest China. Each of the six ASUs has a production capacity of around 100,000 m^3/h. Shenhua Ningxia requires the oxygen to produce 4 million m.t./yr of coal-derived products — mainly liquid fuel.

Ma'aden announces significant phosphate expansion

December 22, 2016 — The Saudi Arabian Mining Co. (Ma'aden; Riyadh, Saudi Arabia; www.maaden.com) will execute a project to increase manufacturing capacity of phosphate fertilizers gradually over the next seven years. Upon completion of this project, production will be increased by 3 million m.t., reaching a total capacity of nearly 9 million m.t./yr for phosphate fertilizer products.

Formosa-Mitsui JV to expand electrolyte-solution production capacity

December 21, 2016 — Formosa Mitsui Advanced Chemicals Co. (FMAC), a joint venture (JV) of Mitsui Chemicals Inc. (Tokyo; www.mitsuichem.com) and Formosa Plastics Corp. (Kaohsiung City, Taiwan; www.fpc.com.tw), plans to increase the capacity of its electrolyte-solution production facilities. Currently, the plant's production capacity is 1,500 m.t./yr, and the planned expansion will increase the capacity to 5,000 m.t./yr. Commercial operations of the expansion are set to commence in November 2017.

Mergers & Acquisitions

Braskem agrees to sell quantiQ distribution business

January 11, 2017 — Braskem (São Paulo, Brazil; www.braskem.com.br) signed an agreement with GTM do Brasil, a subsidiary of GTM Holdings S.A., through which it will sell a 100% interest in its subsidiary quantiQ, one of Brazil's largest chemical-product distributors. The transaction is worth around $172 million.

Toray forms JV with Mitsui Sugar for cellulosic-sugar manufacturing process

January 5, 2017 — Toray Industries, Inc. (Tokyo; www.toray.com) will establish a JV company with Mitsui Sugar Co. for manufacturing cellulosic sugar via a new membrane-based process from the surplus bagasse generated at sugar mills. The new JV will be called Cellulosic Biomass Technology Co. (CBT), and will have headquarters in Bangkok, Thailand. Toray will hold a 67% interest in CBT, with Mitsui Sugar owning the remaining 33%.

LINEUP

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Altana acquires Formulated Resins business from Solvay

January 4, 2017 — Altana AG (Wesel, Germany; www.altana.com) acquired the Formulated Resins business of Solvay S.A. (Brussels; www.solvay.com), which sells products primarily under the Conap brand name. This business generated sales of around $20 million in 2015. With the acquisition, Altana takes over a research and production facility in Olean, N.Y.

Huntsman sells European surfactant assets to Innospec

January 3, 2017 — Huntsman Corp. (The Woodlands, Tex.; www.huntsman.com) completed the sale of its European surfactants business to Innospec Inc. (Littleton, Colo.; www.innospecinc.com) for $225 million. Huntsman retained certain core products and entered into arrangements with Innospec to allow Huntsman to continue marketing some products.

Evonik acquires Air Products' specialty additives business

January 3, 2017 — Evonik Industries AG (Essen, Germany; www.evonik.com) has completed the activities to acquire the specialty additives business (Performance Materials Division) of Air Products and Chemicals Inc. (Lehigh Valley, Pa.; www.airproducts.com) for $3.8 billion (approximately €3.5 billion). All relevant antitrust authorities have approved the transaction and the integration of the acquired business is underway.

GlyEco acquires glycol distillation assets from Dow

January 3, 2017 — GlyEco, Inc. (Phoenix, Ariz.; www.glyeco.com) completed the acquisition by its subsidiary Recovery Solutions & Technologies Inc. (RS&T) of certain glycol distillation assets located in Institute, W.Va. from Union Carbide Corp., a wholly owned subsidiary of The Dow Chemical Co. (Midland, Mich.; www.dow.com).

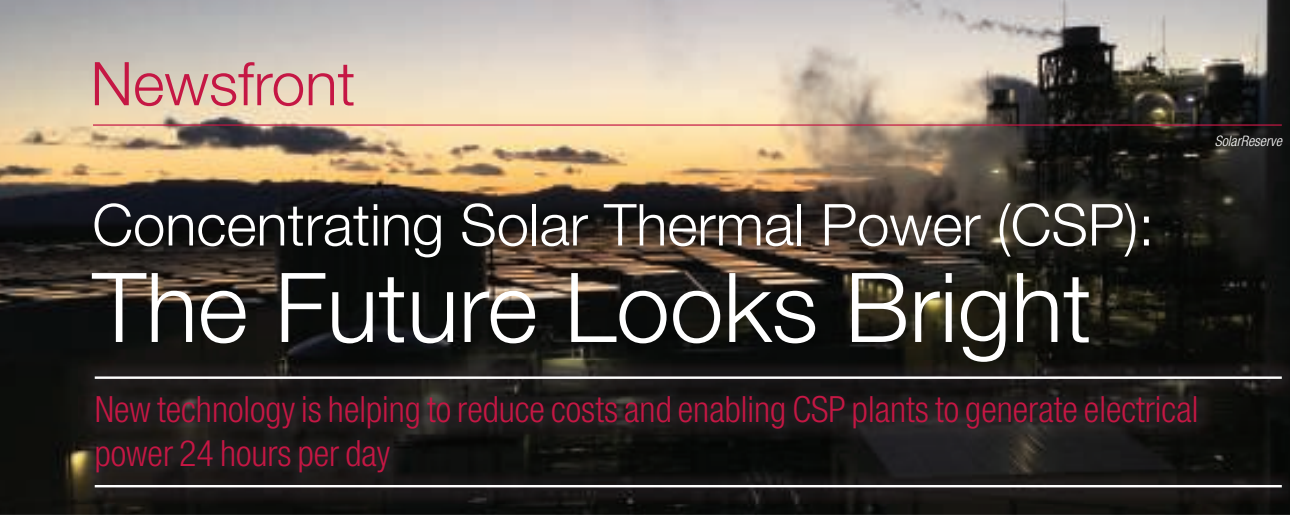
Alpek acquires petrochemicals assets from Petrobras

January 3, 2017 — Alpek S.A.B. de C.V. (San Pedro Garza Garcia, Mexico; www.alpek.com) has signed an agreement with Petrobras (Rio de Janeiro, Brazil; www.petrobras.com) for the acquisition of Companhia Petroquimica de Pernambuco (Petroquímica Suape) and Companhia Integrada Têxtil de Pernambuco (Citepe) for $385 million. The acquired companies operate an integrated facility in Ipojuca, Brazil with an installed capacity of 700,000 m.t./yr of purified terephthalic acid and 450,000 m.t./yr of polyethylene terephthalate. Citepe also operates a 90,000-m.t./yr texturized polyester-filament plant on the site.

Linde and Praxair announce intention to merge

December 20, 2016 — The Linde Group and Praxair, Inc. (Danbury, Conn.; www.praxair.com) intend to combine in a merger of equals under a new holding company through an all-stock transaction. Based on 2015 reported results, the combination would create a company with revenues of approx. $30 billion, prior to any divestitures, and a current market value in excess of $65 billion. Corporate functions would be appropriately split between Danbury and Munich. ■

Mary Page Bailey



SolarReserve

Concentrating Solar Thermal Power (CSP): The Future Looks Bright

New technology is helping to reduce costs and enabling CSP plants to generate electrical power 24 hours per day

If you are keeping upwith the news, then you are aware of the quiet revolution that is taking place in the power-generation market, especially in some countries. Renewables, such as solar and wind are becoming increasingly competitive with fossil fuels, and in some countries, accounting for a larger (albeit still small) share of electricity production. Germany's energy-transition (*Energiewende*) policy (published in 2010), for example, aims for a 55–60% share of renewable energy in gross electricity consumption by 2035.

Germany's *Energiewende* and other national initiatives have been a major boom for research and development (R&D) and a driver for industry to further develop wind, solar and other renewable energy technologies.

When it comes to solar energy, photovoltaic (PV) solar panels have played the dominant role for generating electricity thus far, and the fierce competition in the PV market has driven down costs (see Editor's Page, p. 5), as well as driven some manufacturers out of business. However, there is another, less-talked about, but important solar-power technology that has been around for decades and offers a major advantage over PV and wind: concentrating solar thermal power (CSP; see sidebar below).

Storage, the CSP advantage

The main advantage of a CSP plant is that it produces grid-friendly, dispatchable electricity, says Kevin Smith, CEO at SolarReserve (Santa Monica, Calif.; www.solarreserve.com). That means electricity is produced quickly to meet the demand — the same as any conventional steam-driven turbine power plant, he says. That's because CSP plants being built today have the ability to store large amounts of heat using molten salt technology. This ability to store thermal energy instead of storing electricity (as may be done by PV and wind generation with

FIGURE 1. The Crescent Dunes CSP plant, which has been operating in Nevada since late 2015, continues to generate steam for power generation, even at night, thanks to molten-salt technology

IN BRIEF

CSP TECHNOLOGY TODAY

Unlike solar PV panels, which collect sunlight and directly convert it into electricity, a CSP plant instead collects sunlight and converts it to heat. This thermal energy is then used to make steam to generate electricity. Today, there are basically four commercially available CSP technologies, which differ in the way they concentrate the sunlight. *Line focusing systems* include *parabolic* mirrors and planar *Fresnel* reflectors. For both systems, glass tubes are located along the focal line. The tubes are coated with a black absorbent material that converts the sunlight into heat, which is carried away by a heat-transfer fluid circulating through the tubes. The collected thermal energy is then used to make steam.

Point concentrators include power towers and dish systems. For *power towers*, a field of single-focus mirrors (heliostats) track the sun to always focus sunlight onto a single receiver at the top of a tower, and the heat delivered to a steam generator via a heat-transfer fluid circulating up and down the tower. With *dish technology*, a dish-shaped mirror tracks the sun and focuses the light to a receiver located at the focal point, and the heat is directly converted to steam, which is used to drive an on-board engine, such as a Stirling or Braydon engine. The power capacity is raised by increasing the number of dish systems.

There are over 130 CSP projects worldwide that are described in a database maintained by the U.S. Dept. of Energy's National Renewable Energy Laboratory (NREL; Golden, Colo.; www.nrel.gov) for SolarPaces (Tabernas, Almeria, Spain; www.solarpaces.org), a technology network of the International Energy Agency (IEA; Paris, France). Of the CSP projects included, 99 are operating and 18 under construction. Parabolic trough CSPs have historically dominated the market (88 projects), but power-tower technology (29 projects) is becoming increasingly important due to its inherent ability to store energy at higher temperatures.

At the end of 2016, there were 5 GW of CSP installed worldwide, according to the International Renewable Energy Agency (IRENA; Abu Dubai, United Arab Emirates; www.irena.org). Spain, with 50 CSP plants now operating, accounts for 2.3 GW, while the U.S. accounts for about 1.7 GW, although an additional 1.7 GW now under construction could push the U.S. back into the lead. Meanwhile, China recently announced a major push to add 1.4 GW of CSP capacity by 2018, and 5 GW by 2020. Last September, the National Energy Admin. of China (Beijing; www.nea.gov.cn) announced its list of 20 CSP pilot projects (9 tower, 7 trough, 4 Fresnel), which will be designed and built by a number of Chinese companies, some in collaboration with international companies, including the U.S. and Australia.

IRENA projects an increase in installed CSP capacity to at least 45 GW by 2030 under its reference case or even 110 GW by 2030 with a more aggressive renewables-penetration scenario to limit global temperature increases to 2°C, says BrightSource Energy's Joe Desmond. ❑

SolarReserve

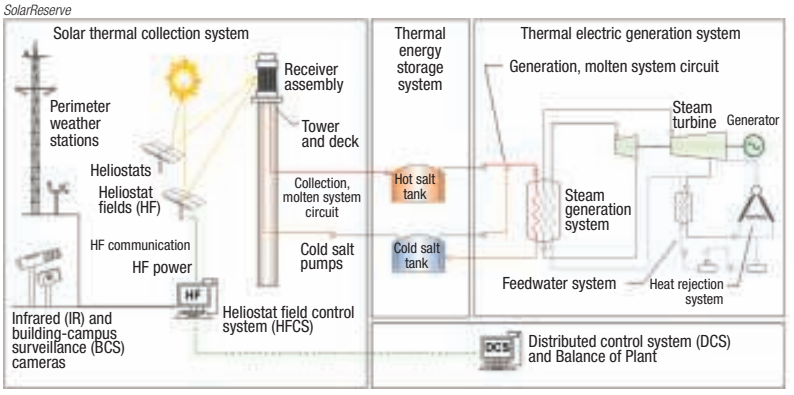


FIGURE 2. This diagram shows the principles of operation of a tower CSP plant with energy storage

battery storage) has been the "holy grail," says Smith. The electricity from a CSP is not only dispatchable, but it is dispatchable 24 hours per day (Figure 1). "No external backup fuel is required to run the plant during the night."

SolarReserve's tower power technology (Figure 2) uses molten salt — a mixture of sodium and potassium nitrates — as both the heat transfer fluid and as the energy storage medium. The molten salt (at 600°F; 315°C) is pumped up the tower (about 600-ft height) to the receiver, where it is heated by the concentrated sunlight to about 1,050°F (566°C). Around 60 million pounds of molten salt is stored in stainless-steel tanks, which are insulated so that virually all of the heat can be available when needed for making steam.

The company's first commercial unit — the 110-MW Crescent Dunes project in Tonopah, Nevada — started up in late 2015, and won *Power* magazine's plant of the year award last year. Since then, SolarReserve has a number of new plants in the works, including a 100-MW tower CSP for the Redstone project in Postmasburg, South Africa, which will use molten salt technology for 12 h of storage when operational in 2018.

The use of molten salt technology in tower CSP plants was pioneered by Torresol Energy S.A. (Madrid, Spain; www.torresolenergy.com), with its first commercial plant — the 19.9-MW Gemasolar CSP plant in Seville, Spain — that was commissioned in 2011. That plant's molten salt storage tank permits up to 15 h of electricity generation without any solar feed.

Other companies, including Abengoa (Seville, Spain, www.abengoa.com) and BrightSource Energy (Oakland, Calif.; www.brightsourceenergy.com) offer CSP technology with molten salt storage. For example, Abengoa is constructing a 110-MW CSP plant in the Atacama Desert, Chile that will use a heated-steam CSP tower and molten salt technology for up to 17.5 h of thermal energy storage (Figure 3). The company has also developed this energy storage system in one of the world's largest parabolic trough CSP plants in Solana, Arizona, with a total capacity of 280 MW and 6-h storage capacity, which started up in 2013.

Abengoa

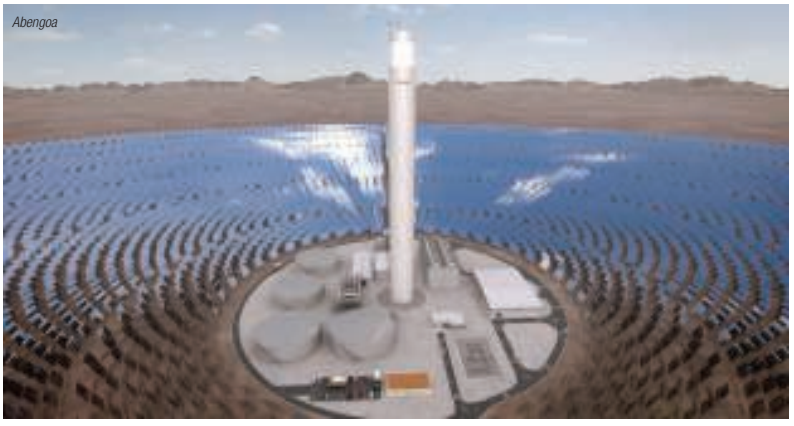


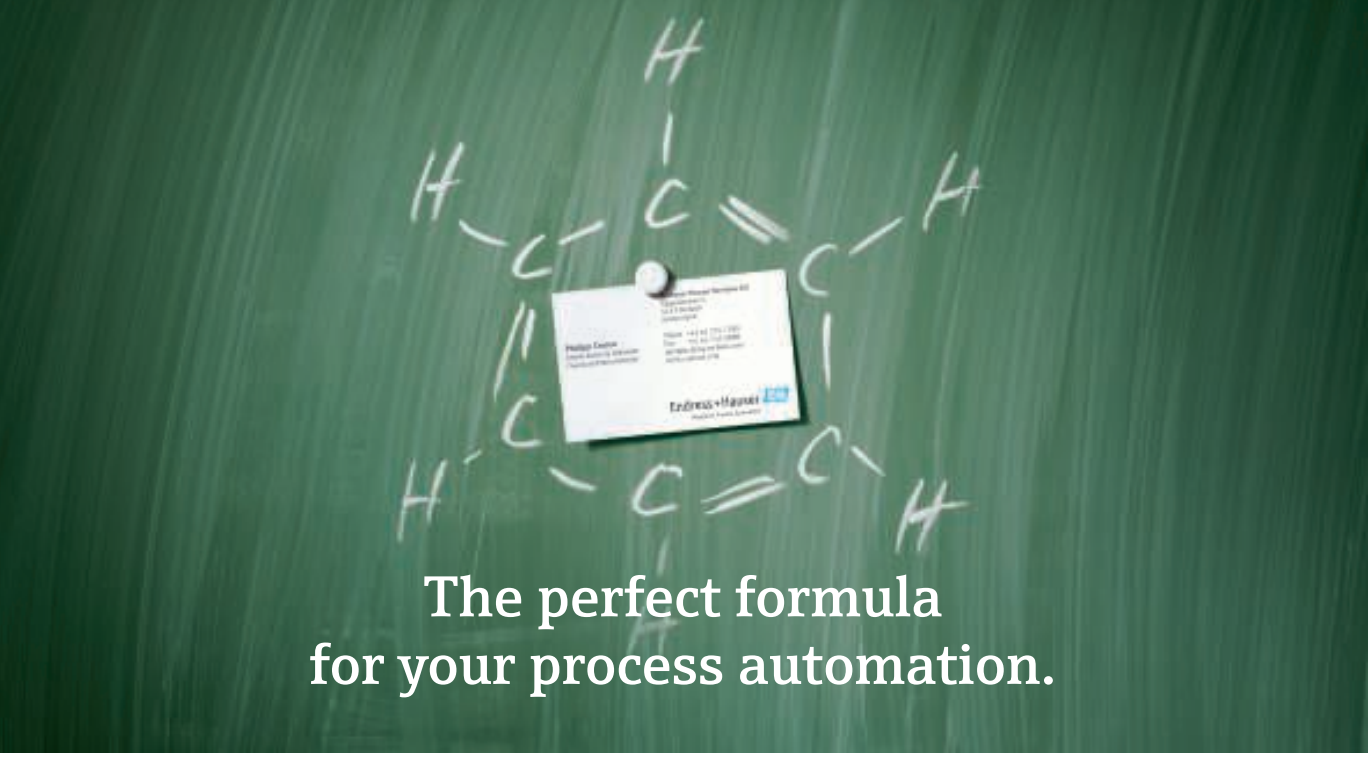
FIGURE 3. Abengoa is developing South America's first CSP plant in Chile. The plant will use an advanced storage system enabling it to generate electricity for up to 17.5 h without direct solar radiation

Efforts to cut costs

Despite its advantages over PV and wind generation, a CSP plant with energy storage is still very expensive, and there is now a major push to reduce costs. For example, in 2011, the U.S. Dept. of Energy (DOE; Washington, D.C.; www.energy.gov) launched its Sunshot program (https://energy.gov/eere/sunshot/sunshot-initiative), which is targeting a levelized cost of electricity (LCOE) for CSP at $0.06/kWh (unsubsidized) by 2020, which represents a 70% reduction from the 2010 baseline.

Already, experience gained from operating CSP plants has led to cost reductions. For example, in a tower CSP plant, the heliostat field can account for about 50% of the investment costs. But thanks to design refinements to enable more efficient capture of light, improved accuracy of the mirrors, better drives and wireless technology, "we have been able to cut the costs of heliostats by 30–40%," says SolarReserve's Smith. "Because we are always making improvements, the cost of our second plant in South Africa is about 25% less expensive than our first CSP in Nevada," he says.

BrightSource Energy's senior vice president of marketing and government affairs Joe Desmond agrees that "there have been advances in all areas of solar thermal systems, including thermal technology, receiver design and heliostat design, to name a few." The company's fourth-generation technologies, which are being implemented in the 121-MW Ashalim Solar Thermal Power Station, located in Israel's Negev desert, include a new heliostat design with fewer components and easier assembly that improves performance and lowers costs, explains Desmond. "The latest design measures 4 × 5.2 m — 25% larger compared to Ivanpah." Wireless field communication and control — a first for the CSP industry — is another innovation, he says.



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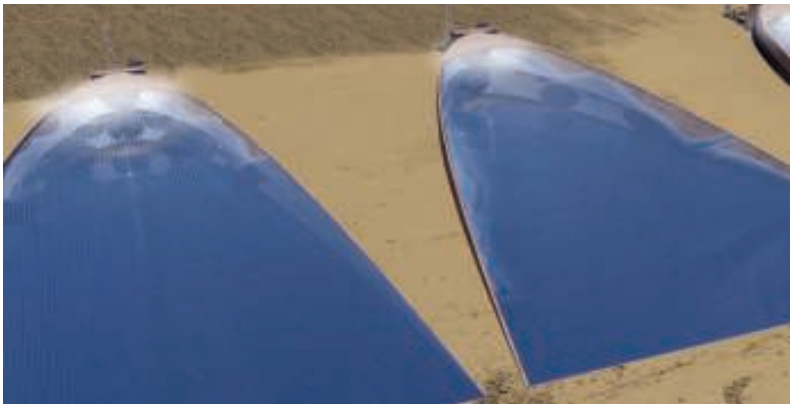


Figure 4. Digital Glass can provide new ways to harvest sunlight. Here are football-field-sized solar thermal power plants that use microfluidic-based solar collector panels that exploit electronically modulated invisibility to harvest sunlight dynamically

At Ashalim, each of the 50,600 heliostats positioned in the 3.15-km^2 solar field will communicate wirelessly with the company's solar field integrated control system (SFINCS). "The wireless system reduces cabling by as much as 85% in the solar field, reducing costs and accelerating the construction schedule," he says.

Another cost-saving measure is the use of dry (or air) cooling. In thermal steam systems, the superheated steam inside the boiler pipes must be cooled and condensed back into water in a closed-loop system. Dry cooling uses an air-cooled condenser comprising many large fans to circulate air over the pipes to cool and condense the steam. In contrast, a wet cooling system circulates water across the pipes, which can lead to large water demands.

All CSP plants being bid today utilize dry cooling, which uses 95% less water than traditional wet-cooling technologies, say Desmond. For example, the Ivanpah Solar Electric Generating System utilizes dry cooling. "Located in California's Mojave desert, Ivanpah uses 50 acre-feet of water annually, which is equal to the amount of water consumed annually at one hole of the golf course located next to the facility," he says.

Higher temperatures

In power generation, operation at higher temperatures can mean higher efficiencies. This is also true with CSP plants. For this reason, SolarReserve, for example, is working on an advanced tower-receiver design that can operate at 1,400–1,500°F (760–816°C), says Smith.

Parabolic trough technology uses oil-based synthetic heat-transfer fluids (HTFs) that are limited to 400°C. As a result, storage temperatures for trough CSP plants range between 280–400°C, compared to over 550°C for tower plants. To overcome this barrier, the German Aerospace Center (DLR; Cologne, Germany; www.dlr.de) is involved in a number of projects. For example, a recent study (published in *ScienceDirect* in 2015) concluded that a new silicon-based HTF — Helisol from Wacker Chemie AG (Munich, Germany; www.wacker.com) — forms less low-boiling and gaseous compounds at 425°C compared with currently applied HTFs at 400°C. A techno-economic comparison showed that the LCOE can be reduced by 5% using silicone fluids.

Last summer, a two-year, DLR-led international project began with the aim to demonstrate the use of molten salts in parabolic-trough CSP plants. "Depending on the salt mixture, upper process temperatures of up to 550°C are possible," says project manager Michael Wittmann from DLR's Institute for Solar Research, Line Focus Systems. As part of this project, a demonstration plant will start up later this fall in Èvora, Portugal. The plant will have a thermal capacity of 2.2 MW (one full loop with four parabolic trough collectors) plus a steam generator capable of delivering 1.6 MW, says Wittmann. "This is the just-before-market scale," he says.

Among the partners, TSK Flagsol Engineering GmbH (Cologne, Germany; www.flagsol.com) will adapt the design of its Helio Trough collector and demonstrate its applicability. Steinmüller Engineering GmbH (Gummersbach, Germany; www.steinmueller.com) will install and test its once-through steam generator, heated with molten salt. The once-through design allows superheated-steam parameters for commercial application. Wittmann says the molten salt technology has the potential to reduce the costs of a trough CSP plant by up to 33%.

Other developments

Meanwhile, Mitsubishi Hitachi Power Systems, Ltd (MHPS; Yokohama, Japan; www.mhps.com) is scheduled to complete verification testing this month on its new sunlight and thermal collecting system, which started last August at the company's Yokohama Works. The proprietary design is a hybrid system that combines a low-temperature Fresnel evaporator and a tower-type superheater that uses heliostats. This design enables the production of higher-temperature steam at lower cost compared to conventional CSP systems. In this configuration, about 70% of all concentrated sunlight is collected by the Fresnel evaporator — which is low in cost — to make steam at 300°C. The remainder of the sunlight is collected by the super heater, which will increase the temperature of the steam to 550°C.

Another interesting development (among many others) is a DOE Sunshot Initiative that began last July at Lawrence Livermore National Laboratory (LLNL; Calif.; www.llnl.gov), in collaboration with Giant Leap Technologies (GLT; Richmond, Calif.; www.giant-leap-tech.com). The so-called Collects project aims to further develop GLT's Digital Glass technology (Figure 4) as a new way to harvest sunlight. Digital Glass has the ability to replace today's heliostats with thin, transparent panels using a fraction of today's materials, while also drastically reducing the area needed for solar power plants by a factor of five to ten for the same energy harvest, says LLNL. ■

Gerald Ondrey

Making a Clean Sweep

Good housekeeping results in a better safety record and higher product quality

Safety is a high priority in the chemical process industries (CPI). However, safety programs tend to focus more on larger, regulated concerns, such as personal protective equipment, chemical handling, storage and labeling and environmental compliance, while safety issues related to good housekeeping often get less attention. Unfortunately, many smaller-scale incidents (think slips and falls and minor injuries) that occur in a chemical facility are directly related to poor housekeeping. For this reason, experts stress the importance of proper housekeeping procedures and tools. And, if an improved safety record isn't enough incentive to get your facility into "white glove" condition, there's also a strong correlation between proper housekeeping and product quality.


Alfa Laval Tank Cleaning

FIGURE 1. The Gamajet tank cleaning system uses rotary impingement to provide a 360-deg, reliable and effective clean using high-impact jets to scour tanks clean

Spills and other dirty hazards

"The buildup of spills, dust and other hazards will certainly become safety issues if the cleanup of process and other facility areas is not a high priority. Personnel will be injured and end product will start to suffer," says Rick Morgando with Kafko International, Inc. (Skokie, Ill.; www.kafkointl.com), which manufactures Oil Eater-brand products. "The manager of the facility has to view the relationship between housekeeping and safety to be as important of an issue as the quality of the product they are producing. Furthermore, housekeeping, safety and product quality are all connected."

Andrew Delaney, R&D product manager with Alfa Laval Tank Equipment (Exton, Pa.; www.gamajet.com) agrees. "It all goes hand in hand. You can't make good product on dirty equipment or in a dirty tank. You lose consistency, you lose yield of the process and you run the risk of cross contamination," he says. "Because processors know this is true, they often send their people into tanks to spot-clean the areas missed by outdated methods of tank cleaning, but confined-space entry is a huge safety risk."

And, the fact that it is chemicals being processed (and, therefore, spilled) ups the ante on housekeeping because the materials may be corrosive, hazardous or dangerous, and must be handled in a manner that adheres to strict regulatory guidelines. Stephen Preece, technical director with Madison Chemical Co., Inc. (Madison, Ind.; www.madchem.com), which blends chemicals from raw materials and produces industrial cleaning products, explains. "We have 1,500 products in our line and a large number of raw materials that we purchase, store, label and handle. There are legal requirements and quality-system requirements and, of course, certain personal preferences that come into play."

In addition to adhering to all the legal and regulatory requirements, attention to housekeeping in the process and production areas is an important safety precaution for his company, as well. "We have large mixing tanks with propeller-type blades. Everything needs to be kept clean and tidy. We need to avoid or immediately attend to liquid spills to avoid slip hazards. We have dry powders and they need to be properly handled to avoid spills because those create dust hazards. Attending to these issues helps us avoid accidents and keeps personnel safe, but it also improves our products because we don't want our finished products contaminated with drips and spills from other raw materials or other products in our line."

He continues: "Safety is key but it all feeds into the whole general quality area.

IN BRIEF

Madison Chemical Co., Inc.

FIGURE 2. To address cleaning stainless-steel process equipment, ReStore Kit provides a combination of several cleaning and surface-preparation products that are suitable for many chemical and food-processing cleaning, surface preparation and passivation applications

You want control of the chemicals you are working with and processing. They shouldn't be in places where they aren't supposed to be for safety and quality reasons. Housekeeping and cleanliness are extremely important and should play directly into the whole ethos of the company. A company that keeps its facility clean and safe for its employees is also likely to make high-quality product."

Not only is it important to focus on keeping the facility clean in order to be safe, but what needs cleaning up and what's being used to clean it are also important considerations. "It has been well established that if areas aren't clean, they will quickly create an unsafe work environment, but it is equally important to understand the risks and limitations of the equipment that you are using to clean up areas, especially in a chemical processing facility where there are hazardous materials and combustible dusts," warns Brian Farno, applications engineering manager with Exair (Cincinnati, Ohio; www.exair.com). "If you aren't using the right tool for the housekeeping task, you may be increasing the risk and adding to the recipe for an accident."

Rite-Hite Door

FIGURE 3. LiteSpeed HZ high-speed door is UL listed for hazardous-rated environments. The door has a Class II, Division 2 listing from UL, carrying a Group Code G and Temperature Code 6, which means it can safely operate in facilities where combustible dusts such as flour, grain, wood, plastic or chemicals are not normally in the air but can be present

Vortec

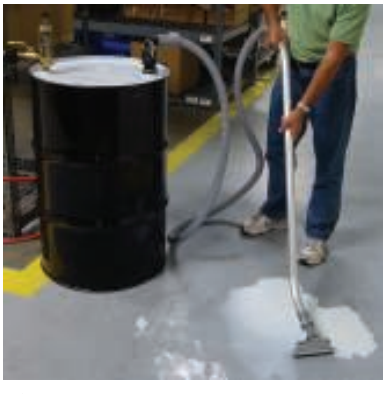


FIGURE 4. The Dual Force Vac Drum uses Vortec technology, which is a two-way, air-powered drum pump that can fill or discharge a 55-gal drum in 2 minutes. It can handle viscous liquids to 1,500 cP, as well as chips and particulate, making it suitable for cleaning solvents, hydraulic oil, liquid spills, liquid transfers and more

Keeping process areas clean

Nowhere is selecting the right tool for the cleaning job of higher importance than on process equipment, says Delaney. "If processors are using outdated tank-cleaning systems like a static spray ball, they aren't cleaning effectively. This means that at the end of the CIP [clean-in-place], processors are sending their employees into tanks to spot clean the areas that aren't being properly reached, and that's just dangerous," he says. "We tell our customers, 'If you know a better cleaning method, one that will allow you to avoid sending people into the tanks, you owe it to your employees to use it.'"

He says not only is there safety risk associated with employees physically climbing into and out of tanks, but also there are often dangerous fumes and CO_2 levels associated with the materials being processed that can harm or kill people inside a tank. In order to increase the cleanliness of tanks and reduce the associated safety risks, he suggests updating from old-school static spray balls to a more modern tank cleaning method, such as rotary spray heads or more advanced impingement cleaning systems. Besides reducing the need to send personnel into tanks, Delaney says there will also be a boost in product quality and efficiency.

"The main factors associated with cleaning are time, temperature, chemicals used and mechanical action," he explains. "When you increase any one of those four forces, the others have to decrease. For example, making the move from a static spray ball to a rotary spray ball will increase the mechanical force by 30%, which will decrease the other factors by the same amount. This allows you to clean the tank in less time with less chemicals and lower temperatures."

He adds that impingement cleaning devices, also known as rotary jet heads, increase the impact by upwards of 70%. "If a spray ball takes and hour, the impingement cleaning system will take 8 minutes. What can you do with 52 extra minutes of process time?"

In addition to the time saved, the

Kafko International

FIGURE 5. The Oil-Eater Tuff Rug is designed to prevent slips and falls by absorbing oil leaks, dirt and grime in forklift aisles, around equipment and in high-traffic process areas

company's Gamajet rotary impingement tank cleaning technology (Figure 1) also provides more mechanical force, leading to a more thorough cleaning job, which increases safety because spot cleaning is no longer necessary. "We emphasize the importance of eliminating confined space entry," says Delaney. "There is absolutely no reason to send people into tanks anymore, which leads to a safer facility that produces better product."

Keeping stainless-steel process equipment clean in chemical and food processing facilities is also an important housekeeping task in processes that need to keep product quality high and consistent, says Preece. "Facilities that process stainless-steel parts occasionally get weld burns or other marks and contamination, which need to be addressed," he says. "When this happens, stainless-steel parts need to be repassivated and contaminants like rust, metal chips and grease stains need to be cleaned." To address cleaning stainless-steel process equipment, Madison Chemical created its ReStore Kit (Figure 2), which is a combination of several cleaning and surface-preparation products that are suitable for many cleaning, surface preparation and passivation applications. The kit allows users to clean, etch and remove surface oxides and prepare a variety of metal surfaces for processing, reducing contamination issues and improving product quality.

Zach Anhorn, product manager with Rite-Hite Doors (Milwaukee, Wis.; www.ritehite.com), says that since process areas must be kept clean, as well as safe, maintaining barriers via automated machine guarding can reduce potential unsafe interaction between employees and the process, while still providing access as needed. For this reason, Rite-Hite offers Defender Cell point-of-operation and perimeter guarding, which reduces impact from rotating or moving parts, flying debris and unexpected machine movement. It adheres to Occupational Safety and Health (OSHA) standards related to hazard containment and employee protection. "This automated guarding system can be built around specific equipment with which you don't want employees to come into contact, but with which they may still need access," he says. "It can be configured to any type of equipment to provide rigid fencing around the equipment while still allowing access via a machine-guarded door to protect employees from the process."

Combustible and other dusts

Dust can pose a variety of housekeeping and safety challenges, including ignition issues with combustible dust or respiratory issues with other dusts. Rite-Hite also offers a solution for clean areas with combustible dust concerns in the form of its LiteSpeed HZ high-speed door (Figure 3), which is Underwriters Laboratories (UL) listed for hazardous-rated environments. The door has a Class II, Division 2 listing from UL, carrying a Group Code G and Temperature Code 6, which means it can safely operate in facilities where combustible dusts, such as flour, grain, wood, plastic or chemicals are not normally in the air but can be present. All electrical components are within a dust-tight enclosure, which makes it safe to use in these special environments. Other safety features include a soft

Acoustiblok

FIGURE 6. Acoustiblok soundproofing material is a thick, advanced sound barrier material that is placed between a noise source and the noise receiver. The viscoelastic, flexible, dense polymer material with a high-density mineral content contains no barium, lead or asbestos

breakaway bottom and reversing slack sensor to reverse the door's course if an obstruction is sensed.

Non-combustible dusts may also pose a safety issue, so companies such as Exair provide High-Efficiency Particulate Air (HEPA) vacuum cleaners (vacs) to prevent respiratory problems, while keeping the facility free of contaminants, says Exair's Farno. The company's compressed air-operated Heavy Duty HEPA Vac attaches to an ordinary 55- or 110-gal open-top drum to turn it into a HEPA-quality industrial vacuum cleaner. The HEPA Vac has been engineered to filter contaminants to HEPA requirements in dusty environments requiring frequent cleaning. The economical, easily maintained pre-filter stops the larger particles of debris while the HEPA filter handles smaller matter. The filters are 100% tested in accordance with IEST-RP-CC-007 for minimum 99.97% filtration at the 0.3 micron level to meet HEPA standards. This vacuum uses no electricity and has no moving parts, eliminating the risk of electric shock.

Spill- and slip-free floors

Along these lines, Steve Broerman, engineering manager, says his company, Vortec (Cincinnati, Ohio; www.vortec.com), offers the Dual Force Vac Drum pump (Figure 4), which operates on compressed air with no moving parts and requires no electricity for liquid material handling and spill clean up in locations that need to keep floors and equipment free from spills, but that might have concerns about traditional vacuum technologies. "In a chemical facility there are potential hazards such as vapors and dusts that would be easily ignited with the spark from an electric motor," he says. "Our product doesn't use electricity to operate so it's generally safe in those environments."

The vacuum uses Vortec technology, which is a two-way, air-powered drum pump that can fill or discharge a 55-gal drum in 2 min. It can handle viscous liquids to 1,500 cP, as well as chips and particulate matter, making it suitable for cleaning solvents, hydraulic oil, liquid spills, liquid transfers and more.

And, absorbent products are also available to prevent slips and falls in areas where spills and drips are inevitable. Kafko's Morgando suggests The Oil-Eater Tuff Rug (Figure 5), which is designed to prevent slips and falls by absorbing oil leaks, dirt and grime in forklift aisles, around equipment and in high-traffic process areas. Made of 100% recycled materials, Tuff Rug is underside-fused through a heat and pressure process to ensure a high level of absorbency while also retaining the tear resistance required.

Controlling noise pollution

In process facilities, a worker's overall noise exposure may come from an individual machine, but noise from other machinery or processes may contribute to the overall noise level, says Lahnie Johnson, president and founder of Acoustiblok (Tampa, Fla.; www.acoustiblok.com). And, there is a direct correlation between controlling noise pollution and increasing safety and process efficiency. "Sound-abatement products can not only reduce the potential liability for hearing loss and OSHA fines, but also reduce the effects loud noise can have on production output," says Johnson. "Studies show it also reduces worker injuries and deaths caused by employees being distracted by loud noises."

However, depending on the facility, the chemicals in the plant may have a destructive effect on certain types of sound-abatement materials. "For safety reasons, non-flammable, hydrophobic, non-corrosive materials are a must," notes Johnson.

The company's Acoustiblok soundproofing material is a thick, advanced sound barrier material that is placed between a noise source and the noise receiver (Figure 6). It's a proprietary viscoelastic, flexible, dense polymer material with a high-density mineral content that contains no barium, lead or asbestos, and has been used successfully in many chemical facilities.

"It's important to remember that a lot of housekeeping and safety in a chemical processing facility is governed by regulations and there's a long list of legal requirements that you have to meet," says Madison Chemical's Preece. "So you have to put that together with a proactive health, safety and housekeeping policy; it keeps the facility safer for your employees and helps you make better products in less time for your customers. It's a win-win situation." ■

Joy LePree

Focus on Pressure Monitoring and Control

Aura Controls

Alicat Scientific

Endress+Hauser

Emerson Process Management

Compact regulator is designed for analytical instruments

The EX2 Series Control Station (photo) is a flexible, small-footprint, gas-delivery system that includes a dual-stage regulator, mounting bracket and flexible hose. It is designed for applications such as calibration systems, gas panels and analytical instrumentation. The device provides primary control for inlet pressures up to 3,000 psig. Its streamlined design minimizes leak pathways and internal volume, enabling efficient purging and safe calibration when used with hazardous gas mixtures, says the company. — *Aura Controls, Virgina Beach, Va.*
www.auracontrols.com

Instrument family enjoys expanded protocol options

This company has expanded the communications-protocol offerings on its pressure, flow and liquid instrumentation products (photo), adding EtherNet/IP and DeviceNet as options. The recently added industrial automation protocols enable integration of instruments from this manufacturer with programmable logic controllers (PLCs) running EtherNet/IP or DeviceNet. Realtime data — including mass flow, volumetric flow, pressure, temperature, selected gas calibration, setpoint and totalized flow of gases — can be read centrally by the PLC and used to manage controllers and meters. With response times as low as 100 ms, controllers rapidly and precisely monitor and control parameters in many CPI applications. — *Alicat Scientific, Tucson, Ariz.*
www.alicat.com/ethernetip

These pressure transducers are designed for hygienic use

Cerebar PMP11, PMP21 and PMP23 pressure transducers (photo) measure pressure up to 6,000 psi and are factory-spanable to meet specific application requirements. The transducers are available with threaded or welded hygienic process connections, to help them meet a variety of industry standards, and they provide 4–20-mA and 0–10-V (d.c.) output signals. The PMP11 and PMP21 pressure transducers measure (with accuracies of 0.5% and 0.3%, respectively) pressures from –15 to 6,000 psi at temperatures from –40 to 212°F. The PMP23 measures pressures from –15 to 6,000 psi at temperatures from 14 to 212°F, with accuracy of 0.3%.— *Endress+Hauser, Greenwood, Ind.*
www.us.endress.com

This wireless transmitter eases installation and operation

The Rosemount 3051S MultiVariable Wireless Pressure Transmitter (photo) is designed to measure two process variables in one installation, helping users to gain greater insight into their processes without increasing installation costs, says the company. The transmitter measures differential and static pressure concurrently, allowing users to reduce pipe penetrations and impulse piping, along with their associated costs. The static pressure sensor is available as either true gage or absolute, which allows for reduced maintenance and calibration costs. Users have instant visibility to their measurements through a non-intrusive, WirelessHART monitoring system. These transmitters have a 10-year stability specification, ensuring a decade of maintenance-free performance, says the company. — *Emerson Process Management, Chanhassen, Minn.*
www.emersonprocess.com

This wireless pressure sensor enables long-range monitoring

The Pressure Scout (photo, p. 25) is an intrinsically safe wireless pressure sensor that expands pressure monitoring and alarm reporting as part of the company's SignalFire Remote Sensing System. It consists of

Note: For more information, circle the 3-digit number on p. 70, or use the website designation.

a pressure sensor integrated with a wireless node and internal battery. It is said to be a low-cost alternative to conduit-wired or other wireless pressure-monitoring solutions, especially for well-tubing and casing pressure monitoring, tank-level monitoring and compressor-station status monitoring applications. The Pressure Scout provides robust, long-range (up to a half mile) transmission to the SignalFire Gateway, where pressure data become available via a Modbus RTU or TCP interface. It operates in temperature ranges from –40 to 80°C, in challenging outdoor environments, maintaining signal strength through variable terrain, structures and weather, says the company. — *SignalFire Wireless Telemetry, Hudson, Mass.*
www.signal-fire.com

This mass flowmeter improves operation and maintenance

Rotamass Total Insight (photo) is a new portfolio of four-wire Coriolis mass flowmeters and transmitters. The Rotamass TI product portfolio consists of six new sensor product lines and two new transmitters that can be configured to suit the needs of the application. These mass flowmeter instruments provide reliable measurements in demanding process environments involving liquids with high viscosity, entrained gases and two-phase flows, under high-pressure or high-temperature conditions, and hygienic or cryogenic environments. — *Yokogawa Electric Corp., Tokyo, Japan*
www.rotamass.com

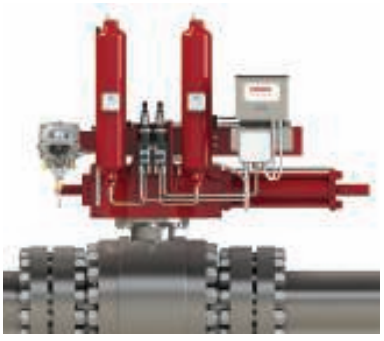
This pressure transmitter has multiple configuration options

The TPM Series digitally compensated pressure transmitter, with ranges from 100 mbar to 600 bars, and a choice of pressure ports and electrical connections, provides high performance with multiple configuration options for a diverse array of industrial applications. This transmitter provides reliable pressure measurements over a temperature range from –20 to 125°C. It is said to be ideal for hydraulic and pneumatic

SignalFire Wireless Telemetry

Yokogawa Electric

Rotork plc



systems, and for fuel and lubricant-pressure sensing, leak detection, filter testing and tank-level sensing. The TPM instrument ensures a ±0.1% span non-linearity, hysteresis and repeatability specification over the full operating temperature range, together with long-term stability (±0.1% span per 12 months is typical), says the company. A choice of pressure ports and electrical connections is available. — *TT Electronics plc, Weybridge, U.K.*
www.ttelectronics.com

Self-contained instrument improves pipeline safety

The Electronic Line Break (ELB; photo) combines pipeline pressure monitoring with intelligent valve control. It continuously monitors upstream and downstream pipeline pressure dynamics to provide early detection of pipeline breaks, and initiate automatic valve actuator movement to an emergency position, based on user-defined parameter. Valve actuator control — selectable as fail-close, fail-open or stay-put — is based on rate-of-drop and rate-of-rise, as well as high- and low-pressure inputs. A remote process-shutdown input with the option to override all functions is also available to drive the valve to the fail position. The device includes an array of programmable alarm and alert indications and other configurable features. The ELB can collect detailed operational data to optimize performance and enhance pipeline safety. — *Rotork plc, Bath, U.K.*
www.rotork.com

Pentair Valves & Controls

Pressure and vacuum valves reduce emissions

The Anderson Greenwood 4000 Series of pressure- and vacuum-relief valves (photo) are compliant with the seventh generation API 2000 standard, which covers normal and emergency vapor-venting requirements for bulk-liquid storage tanks. They are engineered to provide increased flow capacities and will fully open at 10% overpressure, helping to protect tanks from physical damage caused by internal pressure fluctuations, says the company. As a result, the valves can be set more closely to a storage tank's maximum allowable working pressure (MAWP) or maximum allowable working vacuum (MAWV), enabling users to fill and empty tanks more quickly, and operate them at higher pressures, says the company. — *Pentair Valves & Controls, Houston.*
www.valves.pentair.com

Cashco

Back-pressure regulator is available in five sizes

The Model BR back-pressure regulator (photo) is available for a wide range of gases and liquids. With the appropriate options, applications include upstream overpressure regulation of cryogenic liquids, sour gas, industrial gases and chemicals and common industrial fluids, such as water, oil, steam and compressed air. Available in globe or angular porting configurations, the Model BR valve controls inlet pressures up to 200 psig (13.8 barg), in multiple spring ranges, and can be utilized for the majority of industrial pressure-relief applications. The back-pressure regulator is available in five sizes, from 3/8 to 2 in., and can handle materials from 20 to 400°F, with the appropriate body/spring chamber and trim material combinations. — *Cashco, Inc., Ellsworth, Kan.*
www.cashco.com

Tiny differential-pressure sensor opens up new worlds

The SDP3x sensor (photo) is the world's smallest differential-pressure sensor, measuring just 5 mm by 8 mm by 5 mm, according to its manufacturer. It is reflow-solderable and provides extended functionality, such as multiple I2C addresses and interrupts, and fast sampling time. It is designed for high-volume, cost-sensitive applications where size requirements or constraints are essential when measuring differential pressure and mass flow. The digital, fully calibrated and temperature-compensated differential-pressure sensor is available in different versions. For instance, the digital SDP31 sensor and the analog SDP36 sensor measure bi-directional pressure differences up to 500 Pa, while the digital SDP32 and the analog SDP37 measure bi-directional pressure differences up to 125 Pa. — *Sensirion AG, Staefa, Switzerland*
www.sensirion.com ■

Suzanne Shelley

Sensirion

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Parker Hannifin

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Fluid Components International

These pneumatic valves reduce costs for compressed air

Much of a plant's air costs can be associated with inappropriate uses of (or artificial demand for) compressed air. This company's Air Saver Unit (ASU) pneumatic valves (photo) save energy by interrupting the flow of compressed air to blowing end uses at adjustable frequencies. The devices reduce compressed air costs by as much as 40–50% over typical constant-flow applications, according to the manufacturer. Rather than a steady stream of air, an ASU delivers a series of impulses, which offer a significant mechanical advantage. Because the ASU has an opportunity to recover during the "off" period of each on/off cycle, the impulses are delivered with somewhat greater force than a steady stream of air would provide. — *Parker Hannifin Corp., Cleveland, Ohio*
www.parker.com

These venting systems are now approved for metal dust

The Q-Rohr family of indoor flameless-venting products (photo) has recently been approved for use with metal dusts. Q-Rohr systems can also be used with other types of dusts, gases and hybrid mixtures. These indoor systems eliminate the need for relocating dust collectors or other enclosures outside. The system consists of a specialized stainless-steel mesh construction and a rupture disc. An integrated signaling unit connects to any audible or visual alarm and shutdown to alert plant personnel in the event of an incident. If an incident occurs, flames are extinguished, and pressure, noise and dust are reduced to negligible levels. — *Rembe, Inc., Charlotte, N.C.*
www.rembe.us

This valve actuator has safety functions

The TriVAX product family (photo) provides confidence through traceable, proven, transparent safety functions. Along with the company's smart Partial Stroke Test (sPST) integrated into the valve actuator, these functions include a hydraulic-circuit safety system with high-quality components, as well as the flameproof encapsulated housing that fulfills requirements for operation in potentially explosive atmospheres (Ex protection according to ATEX II2GD Ex d IIB T4). Especially with expansive facilities or pipelines, where the butterfly valves are often miles apart, the valves can be controlled via a simple electrical signal. Thanks to integrated interfaces to standard fieldbuses (Profibus PA, HART, Foundation Fieldbus) and the 4–20-mA connection, the TriVAX can be integrated quickly into existing automation concepts. — *Hoerbiger Ventilwerke GmbH & Co. KG, Vienna, Austria*
www.hoerbiger.com

Monitor leaks in pressure-relief valves with this switch device

FLT93L Series FlexSwitch (photo) accurately monitors pressure-relief valves for escaping flow with a flow-sensing switch-alarm assembly that is based on thermal-dispersion technology. The FLT93L switch detects leaking or seeping gas in lines to alert engineers to overpressurization. It issues a programmed alarm during such events. For the system to work properly, the FLT93L must detect low flows and yet avoid issuing false alarms that could seriously impact plant operations. The switch is easy to install and set up, and its voltage output allows users to see into the process and accurately set the desired trip point. Flexible dual relays are configurable by plant technicians for any combination of flow or temperature alarms. The FLT93L's flow accuracy is ±2% of the setpoint velocity over a ±50°F temperature range. — *Fluid Components International LLC, San Marcos, Calif.*
www.fluidcomponents.com

Reduce waste in sealant and adhesive applications

The Hydraulic Fixed Ratio (HFR) Metering System (photo, p. 29) improves throughput and significantly reduces waste and rework in adhesive and sealant dispense applications. The HFR is a meter, mix and dispense system that is capable of processing multiple sealant and adhesive materials. As the system dispenses material, it automatically

fine-tunes and adjusts material flows and pressures to achieve a consistent bead. The system features intuitive controls that allow users to program up to 100 different shot sizes and easily configure temperature control. In addition, the system gives users immediate access to data about material usage, pump cycles and errors. The system is capable of producing either a constant-pressure material output or a constant-flowrate material output. *— Graco Inc., Minneapolis, Minn.*
www.graco.com

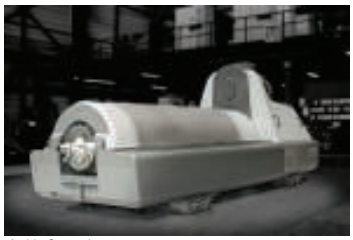
Launch of a new generation of decanter centrifuges

This new generation of decanter centrifuges (photo) will complement this company's existing A-series for industrial, F-series for food and D-series for environmental applications. A key advantage of the new decanters is scalability that can be modified according to users' requirements. This allows maximum flexibility in adjusting standardized machines to meet individual challenges without the risks and costs associated with customized prototype solutions. Capacities range from small to large, and the units handle temperatures from –80 to 180°C, pH-values from 1 to 10 and pressures of up to 6 bars. The decanter centrifuges can be used for slurries or sludge in the feed, and can process many different kinds of slurries, ranging from food to abrasive minerals, from sticky to dusty and from light- to heavy-density material. *— Andritz Separation, Graz, Austria*
www.andritz.com

A new NDIR sensor measures CO in the volume-percent range

FlowEVO CO (100 vol.%) sensors (photo, p. 30) complement the new series of non-dispersive infrared (NDIR) sensors, which already includes the FlowEVO CO (2,000 ppm). The sensors can be used for monitoring CO in many sectors, including gas analysis or emission measurement for fluegas monitoring and process control. In the next few months, ad-

Graco



Andritz Separation

smartGAS Mikrosensorik

ditional CO sensors of the first generation will be replaced successively by the EVO technology. All sensors have an ASCII modbus and remote-terminal-unit (RTU) interface with automatic recognition of the communication settings. The communication speed is up to 38,400 baud. — *smartGAS Mikrosensorik GmbH, Heilbronn, Germany*
www.smartgas.eu

A range of rotameters with corrosion resistance

Instruments in this company's PTFE/PFA Model L range of rotameters (photo) are constructed of rigid frames and inert wetted parts. Made of perfluoroalkoxy alkanes (PFA), polytetrafluoroethylene (PTFE) and polychlorotrifluoroethylene (PCTFE), the meters are resistant to ambient corrosive media. Constructed with or without built-in needle valves, L Meters are easily mountable via panel nuts. Units are individually leak tested. For personnel safety, each L Meter is supplied with a safety shield. Overlapping flow ranges are available for water from 5 mL/min to 45 L/min. The maximum operating pressure is 6.7 bars, and the maximum operating temperature is 250°F. — *Aalborg Instruments, Orange, N.Y.*
www.aalborg.com

Aalborg Instruments

Howden American Fan

Versatile turbo blowers for many applications

This company's line of turbo pressure blowers (photo) is designed for pressures to 80-in. static pressure water gage (SPWG), with capacities up to 8,000 ft^3/min. The fans are available with a wide variety of materials, wheel types, fan arrangements and sensors, making them suitable for higher pressure systems in combustion, air-pollution control, textile fiber stripping and recycling applications, as well as in numerous other chemical, pulp-and-paper, glass and food-processing applications. Application-specific features are added as necessary, including stainless-steel (or other alloy) airstream, corrosion-resistant materials and coatings, high-temperature or spark-resistant construction, companion flanges to match ductwork and pressure gages. The blowers feature heavy-gage, continuously welded housings that are reversible and rotatable. Three inlet types are available — stub pipe, flanged or venturi (standard). — *Howden American Fan Co., Cincinnati, Ohio*
www.americanfan.com

Mehrer Compression

Corrosion management via sensors and cloud analytics

Predictive Corrosion Management (PCM) is a new ATEX-certified digital inspection tool that uses embedded sensors to provide continuous ins pection data and cloud-based analytics of pipe conditions to help operators manage risk, improve uptime and minimize total cost of operation. PCM uses a combination of this company's Rightrax installed ultrasonic sensors with the Predix cloud-based operating system and advisory services to continuously collect and analyze realtime performance data and monitor corrosion-related risk, so facilities can proactively make effective decisions. PCM can identify corrosion before it becomes a problem and can improve the reliability of inspection data, remove manual inconsistencies and enable users to model and predict piping failures due to corrosion and erosion. — *GE Oil & Gas, London, U.K.*
www.geoilandgas.com

This compact compressor can handle raw biogas

The TRZ 1000 (photo) is a completely oil-free, two-stage compressor suitable for use with raw biogas, as well as carbon dioxide, nitrogen, hydrogen and all common process and toxic gases. The lean, vertical design of the crosshead piston compressor allows it to achieve volumetric flowrates up to 600 m^3/h. The water-cooled compressor operates at a suction pressure of up to 2 bars and a discharge pressure of up to 26 bars. The low overall height and low dynamic mass also ensure an operation with lower vibrations, says the manufacturer. All relevant operating parameters, such as temperatures and pressures, are displayed on a panel. The machine is suitable for both belt and direct drive. — *Mehrer Compression GmbH, Balingen,* Germany
www.mehrer.de

A touchscreen table for interactive projects

The Lift & Tilt touchscreen table (photo) is now available with a 65-in. display. The ample workspace of the display and the electrically adjustable height and tilt angle enable group interactivity, ideal for team review of collaborative or data-driven applications. Utilizing a completely flat Ultra-HD 4K screen, the table's base has robust drive mechanics to provide both display lift and tilt to move from completely horizontal to vertical. The table display has high-reliability, low-latency industrial-grade display electronics, and has optional storage compartments for power cable and other accessories. — *Volanti Displays, Morgan Hill, Calif.*

www.volantidisplays.com

Volanti Displays

A clever alternative to vibrating-fork level sensors

The CleverLevel series of level sensors has been expanded with two new variants, the LBFH and LBFI (photo). They are available with two switching outputs, qTeach and a 360-deg output status indicator. Like their predecessors, the level switches are based on frequency deviation technology and are suitable for both hygienic and industrial applications with electrostatic, sticky or pasty media. The convenient qTeach procedure is of great advantage, especially for small installations with simple control systems, says the company. The sensors can be easily adjusted with any ferromagnetic tool, thus making it possible to quickly adapt to changing process requirements on site. The two switching outputs make it possible to set two trigger thresholds. This means two different process steps, such as production and cleaning, or two media groups, such as water and oil, can be monitored with one sensor. — *Baumer USA, Southington, Conn.*

www.baumer.com/cleverlevel ■

Baumer USA

Mary Page Bailey and Gerald Ondrey

Steam Concepts

Department Editor: Scott Jenkins

Steam is commonly used in the chemical process industries (CPI) for process heating, power generation, atomization, cleaning and sterilization, moisturization and humidification, among other applications. This one-page reference provides a refresher for key concepts related to steam.

Pressure-temperature relation

The properties of steam vary significantly depending on the temperature and pressure conditions to which the steam is subject. Steam produced under higher pressures is of higher temperature and carries more energy, but also requires more heat to generate. Steam with higher energy per unit of mass is said to have higher enthalpy, a thermodynamic property of a fluid that is defined as the internal energy of the fluid added to the product of its pressure and temperature. Enthalpy is a measure of the available energy of the fluid, and enthalpies have been calculated for a wide range of steam and saturated liquid conditions. These values may be found in steam tables, and can be graphically represented by a temperature-enthalpy diagram (Figure 1).

Wet steam region

Water can be heated to its boiling point (point A to point B on the curve), which depends on the pressure applied. At its boiling point for a particular pressure, additional energy input will not cause a further temperature change (as long as pressure remains constant) and the steam moves toward point C on the diagram. Steam in this area is termed "wet" since it contains both water vapor and liquid water droplets.

At the boiling point for a given pressure, water changes from a mixture of 100% water/0% steam to a 0% water/100% steam mixture. Wet steam contains a certain portion by mass of liquid water droplets. For example, steam that contains 8% moisture by mass has a dryness fraction of 0.92 and is 92% dry.

If sufficient heat is added to convert all liquid into vapor at a given pressure, the steam is said to be saturated (100% vapor, dry steam; point C). Saturated steam occurs at pressure and temperature conditions that allow water in its vapor and liquid form to exist simultaneously.

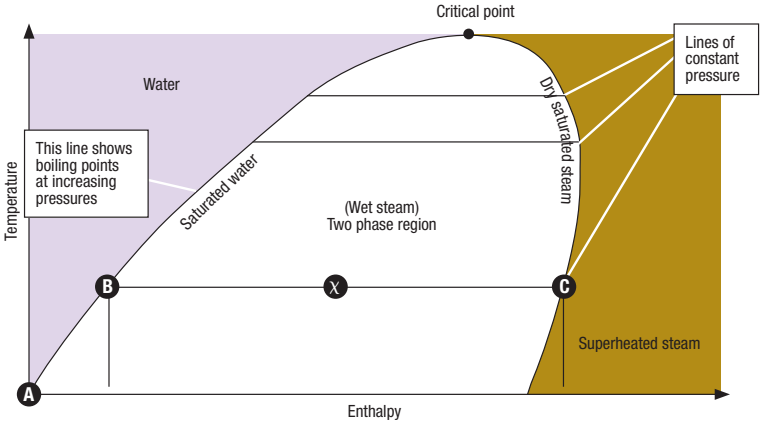


FIGURE 1. A temperature-enthalpy phase diagram illustrates the behavior of steam and the relationships between steam properties

Saturated steam has several properties that make it desirable for process heating, including a high heat-transfer coefficient, which allows a smaller heat-transfer surface area. The heat-transfer capacity of saturated steam is much higher than that of water or superheated steam. Although the temperature of the boiling water and saturated steam within the same system is the same, the heat energy per unit mass is much greater in the steam. Further addition of heat to saturated vapor then increases its temperatures (superheated region). Superheated steam is used to turn turbines in power generation.

Industrial practice

In CPI facilities, it is generally desirable to use steam with the maximum possible dryness fraction. However, perfectly dry (saturated) steam is almost impossible to produce in industrial practice. For steam generated in a boiler, turbulence and splashing cause a small degree of wetness from non-vaporized water molecules, which are carried into the distributed steam. Radiant heat loss also causes some of the steam to condense, necessitating the use of steam traps.

Steam-system users must be aware of potential problems, such as corrosion and scale from impurities in the water, damage to flowmeters and other equipment, and reduced heat transfer. Lower heat transfer rates occur because condensed water can form a film on heat-transfer surfaces, which reduces heat transfer because thermal conductivity of water is much lower than that of steam. Other potential problems include overloading steam traps and water hammer, if the amount of condensed water is too high.

Steam grades

Several grades of steam are common in CPI facilities.

Plant steam. Also known as industrial steam, plant steam is by far the most common form used for general indirect heating in CPI plants.

Filtered steam. Also known as culinary steam, filtered steam is produced by passing plant steam through a high-efficiency filter to remove solid and liquid particles. It also needs to be free of boiler water-treatment chemicals.

Clean steam. Clean steam requires controlled feedwater quality for applications where contamination is not acceptable.

Pure steam. Pure steam is similar to clean steam for use in quality-critical processes. In pure steam, the resulting condensate must meet the standards of the U.S. Pharmacopeia for water-for-injection (WFI), and contain no bacteria or pyrogens. ■

Methionine Hydroxy Analog Production

By Intratec Solutions

Methionine is an essential amino acid that is widely used as an animal feed additive, especially in the poultry market. Hydroxy-methyl butyric acid, also known as methionine hydroxy analog (MHA), is used in animal nutrition as an equivalent to methionine, since it is converted into L-methionine by enzymes inside animals' bodies.

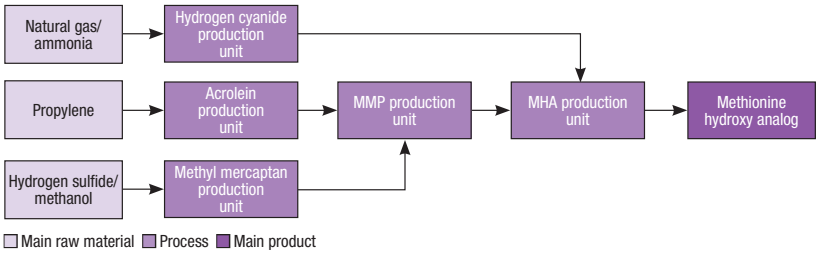


FIGURE 2. Integrated process units for the production of methionine hydroxy analog

The process

In the process described here, liquid MHA is produced from 3-methylmercaptopropionaldehyde (MMP) and hydrogen cyanide. In the first step, MMP is converted to hydroxy-methylthiobutyronitrile (HMBN), which is then hydrolyzed to MHA. Finally, MHA is recovered through solvent extraction. Figure 1 is a simplified flow diagram of this process.

HMBN synthesis. Liquid MMP is continuously fed into the HMBN reactor, while gaseous hydrogen cyanide is fed through the reactor bottom. The reaction of MMP and HCN is catalyzed by a mixture of pyridine and acetic acid. MMP is completely converted, with high selectivity to HMBN, and a few heavier byproducts. The effluent from this reactor is conducted to a nitrogen-stripping column to remove unconverted hydrogen cyanide, the HCN-free stream is then directed to the MHA synthesis.

MHA synthesis. HMBN undergoes hydrolysis in three steps. At first, HMBN is introduced into a continuously stirred tank reactor (CSTR) along with process water and a sulfuric acid stream. HMBN reacts with water to form an amide (2-hydroxy-4-methylthiobutanamide), with sulfuric acid behaving as a catalyst. The effluent from this reactor and additional process water are introduced into a second CSTR, operated at higher temperatures. The amide is hydrolyzed in a reaction with water and sulfuric acid, forming MHA and ammonium bisulfate. The effluent from this second reactor is fed to a plug-flow reactor to guarantee complete hydrolysis of the amide formed in the first step. The resulting aqueous solution is sent for purification.

Purification. MHA is extracted with methyl isobutyl ketone (MIBK). The extract, rich in MHA and solvent, is steam-stripped. The water and solvent are recovered from the top product and a concentrated MHA stream is recovered from the bottom. The final product composition is corrected with process water. The raffinate from the extraction, mostly water and ammonium bisulfate, is also steam-stripped. The water is recovered from the top and an aqueous solution containing ammonium bisulfate is recovered from the bottoms and disposed of as waste.

Economic performance

MHA production cost (including plant operation, product sales, administration, R&D activities and depreciation) is estimated at about $2,400 per ton of product. The scope of this analysis assumes a facility with capacity to produce 160,000 metric tons per year of MHA (88 wt.% liquid solution) from HCN and MMP. The production of these raw materials is usually integrated to the MHA process (Figure 2). The production cost was estimated based on data from the second quarter of 2013 for a plant operating in the U.S.

This column is based on "Methionine Hydroxy Analog Production Process - Cost Analysis," a report published by Intratec. It can be found at: www.intratec.us/analysis/methionine-production-cost. ■

Edited by Scott Jenkins

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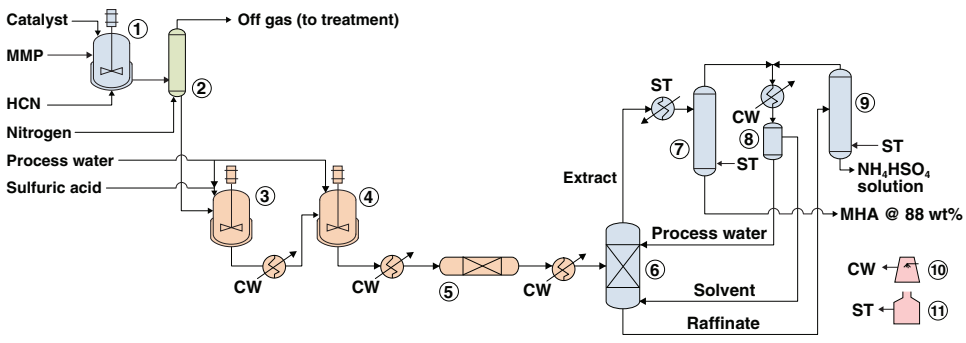

FIGURE 1. Methionine hydroxy analog production from MMP and hydrogen cyanide

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Heat Exchanger Standards for Shell-and-Tube Equipment

Reliable operation of shell-and-tube heat exchangers begins with an appropriate standard. This article provides an overview of those that are applicable

Tom Muldoon, P.E.
American Exchanger Services Inc.

IN BRIEF

Shell-and-tube heat exchangers are the backbone of the power generation, chemical process, petrochemical and pulp-and-paper industries. They are designed for a wide variety of services, from small-engine oil coolers to large nuclear steam generators. Heat exchangers come in many types and styles, but almost all are designed as unfired pressure vessels. Over the years, several industrial standards have been developed to help end users and manufacturers ensure that their heat exchange equipment will be designed with safety and consistency in mind. The principal reason why shell-and-tube heat exchangers have been so successful for so long is their ability to meet critical design performance objectives with such a wide variety of equipment configurations.

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FIGURE 1. Extensive industrial experience with shell-and-tube heat exchangers has helped make them critical in many types of operations

While advancements in micro-channel plate-type heat exchangers have made that class of equipment acceptable, the extensive industrial experience base with shell-and-tube-style heat exchangers, along with the their ability to meet stringent temperature, pressure and mechanical design standards, has made this type of equipment critical to the availability and reliability of many different unit operations (Figure 1).

Achieving mechanical reliability and availability in shell-and-tube heat exchangers, as well as providing units that can be repaired, maintained and cleaned as service factors dictate — whether new or a replacement — starts with choosing a minimum starting point. In most cases, this means choosing an appropriate standard. Because the design possibilities for shell-and-tube heat exchagers are so broad, it is difficult to develop a single, unified industrial standard. This article provides an overview of four standards (or more accurately, three standards and one code) that apply to industrial shell-and-tube heat exchangers.

Shell-and-tube exchanger operation

Heat exchanger tubes come in a variety of sizes, types and materials. Tubes are the conduit for one fluid that keeps the fluid inside the tube (tube-side fluid) separate from fluid outside the tube (shell-side fluid). Almost always, tubes are circular in cross-section and almost always connect to a tubesheet (or two), which secures the ends of the tubes. The tube inner diameter is usually free-flowing and clear.

Tubes are almost always bundled together and surrounded by a shell. The shell keeps

the shell-side fluid in contact with the tubes, which convey the tube-side fluid.

This introduction is intended to convey the vast range of equipment encompassed by the term "shell-and-tube heat exchanger" (Figure 2). There are exceptions and variables for most of the general discussion surrounding this type of equipment. Variables to consider include designs, operations and fluids. Tubes can have internal or external fins, which can have varying heights, depending on the heat-transfer characteristics of the fluids involved. It is also possible to have two separate tube-side or shell-side fluid streams. The shell may be much larger than the tube bundle to allow for boiling. The wide range of equipment design variables complicates standards development.

A feature common to all heat exchangers is the flow of heat from one fluid stream to another. There is always a balance between the streams, called the duty. Whenever a difference in temperature exists, heat will flow from the warmer to the cooler object via one or more heat-transfer modes (radiative, conductive and convective). In some situations, such as fired boilers, the energy of the flames is radiated to the tubing, conducted through the tube wall and convected into the tube-side fluid. In unfired heat exchangers, heat is conducted and convected.

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FIGURE 2. The term "shell-and-tube heat exchanger" incorporates a wide range of equipment variations, such as this model in the shop

Since heat exchangers act through convec-

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FIGURE 3. Finite element analysis was used for the design of the flexible shell element of this large exchanger

tion and conduction, velocity of the fluids has a significant influence on how fast the heat is transferred. The higher the velocity, the higher the heat-transfer rate, but the more energy it takes to get this higher velocity. The smaller the flow area, the higher the velocity.

STANDARDS AND CODE

Three major industrial standards and one code are discussed here. They are the following: TEMA (Tubular Exchanger Manufacturer's Association; Tarrytown, N.Y.; www.tema.org) Heat Exchanger Standards; API 660, a shell-and-tube specification developed by the American Petroleum Institute (API; Washington, D.C.; www.api.org); The HEI (Heat Exchange Institute; Cleveland, Ohio; www.heatexchange.org) Standards for Shell-and-Tube Heat Exchangers; and the ASME (American Society of Mechanical Engineers; New York, N.Y.; www.asme.org) Boiler and Pressure Vessel Code (BPVC). It is incumbent upon the end user of the heat exchanger to specify the appropriate pressure-vessel code that the manufacturer must meet.

TEMA Standards

The TEMA Heat Exchanger Standards (referred to here as TEMA) are the broadest available. Currently in its ninth edition, TEMA is a set of global standards first developed in 1939. Largely mechanical standard, TEMA covers most industries, equipment sizes and services. Its overall scope is to provide for a way to communicate between end-users and manufacturers and designers.

There are three equipment classes within TEMA: R, C and B. TEMA describes the classes as follows:

- R: severe petroleum and related processing applications
- C: commercial and general process applications
- B: chemical process service

TEMA standards are written and published by manufacturers. The information in TEMA is provided to help ensure a common understanding of terms, compatible interfaces and to foster realistic expectations between the end-user and the manufacturer. The focus is on manufacturing and mechanical design. Since the standards are built around three different heat exchanger classes, they allow for some fine-tuning of the standard to meet the needs of the end user. TEMA also provides references for thermal design and fouling. There are cost differences between the three heat exchanger classes. TEMA R units are usually more costly, due in part to their greater corrosion allowance. TEMA R units require 1/8-in. thicknesses for carbon steel and low-alloy steel, while B and C units require 1/16 in. TEMA R units also require a more expensive confined joint flange design. The tube spacing may also be larger on TEMA R than B or C. TEMA R also requires confined gaskets and heavier tie rods. Additionally, there are a few other details that incrementally increase the cost of R over B and C.

While the minimum vessel-wall thicknesses may be thicker in TEMA than for the ASME BPVC or other pressure vessel requirements on low-pressure and low-temperature operations, the thicknesses allow for handling and fabrication. The additional cost of the metal is small and helps equalize fabricators.

The TEMA Standards, provides a three-letter design description for heat exchanger configurations. This is an important function of the standard: it is a quick reference to the mechanical design of the heat exchanger. It combines a front head, shell type and rear head. Choosing a configuration is a function of the services the unit will perform and of end-user preference. It may not be straightforward and will require discussions between end-user and manufacturer.

Tubesheets and tubejoints. All the standards discuss tubesheets, critical components for shell-and-tube heat exchangers that separate the shell side from the tube side. Tubesheets are the components to which the tubes are connected. The tube-to-tubesheet connection (also known as tubejoints) can be welded, roller expanded, explosively welded (or bonded), explosively expanded, hydraulic or a combination. The choice of joint configuration can significantly impact price and reliability. There are also several tubejoint welding options, including strength welds, seal welds and bore welds. TEMA and other reference standards have additional details on the types of joints.

Front stationary tubesheet end. One end of the tube bundle needs to have a stationary tubesheet. The tubesheet provides separation between the shellside and tubeside fluids. The tubesheet on the stationary end is fixed and does not move with thermal differential expansion. It is often gasketed between flanges. At least one nozzle is located in the attaching channel. The ability to open and close the channel with more or less ease is part of the choice of channel design.

TEMA rear-head type. In services with high temperatures and long tubes, differential thermal expansion between the tubes and shell may require a method to provide for their differential growth. This can directly impact the type of rear-head configuration. If the fluid is clean and the tube bundle does not need to be removed to be cleaned, the differential expansion may be accommodated with an expansion joint. Within that decision is the choice of which type of expansion joint should be used. Such expansion joints can be of the bellows type or dished heads. Both options are addressed in TEMA.

If the service of the exchanger requires occasional cleaning of the shell side, a removable design would be chosen. The design pressure, fluid service and gasket requirements may dictate one design compared to another. For instance, a "W" head is not used with a four-tube-pass design due to the need for a pass partition in the return head in which the tubesheet needs to move to account for differential thermal expansion. "W" heads are also not suitable for higher design pressures.

U-tube exchangers may not be appropriate for services in which the tubes need to be cleaned. Fouling and debris can accumulate in the U-bends, resulting in tubes being plugged and prematurely failing. In clean tube-side flow service, the U-tubes can be the most cost-effective approach, since it only requires one tubesheet and only an inlet-outlet channel. This is especially important in high-pressure applications. This return end also requires an even number of tube passes. The choice of the rear head is a function of the cleanliness of the tube-side fluid. If there is a significant temperature difference between the shell-side fluid and tube-side fluid or from startup, a floating head may be desirable. If the shell side is clean and there is no requirement that the bundle be removeable, a fixed tubesheet design (L, M or N) with a shell expansion joint may be more cost-effective and require less maintenance. If the shell fluid is not clean, and the bundle needs to be cleanable, a pull-through head (T) or a split-ring-type return channel (S) may be the best choice.

Shell type. Determining the shell type is a factor largely decided by the thermal design engineer. The way the shell flow transits over and through the bundle can vary with the shell type and the bundle baffling. The installation of longitudinal baffles can also have a dramatic effect on the amount that the temperature profile is corrected for the extent of co-current flow.

An E shell is the most common. It is used where the difference in the outlet temperatures is zero or positive. It is also most common for single-pass counterflow design units when there is a temperature cross of the outlet temperatures. In cases where the E shell would be too long, in an attempt to make a substantial temperature cross, an F shell may be used. The longitudinal baffle can be sealed to the shell ID with "lamiflex" style seals to minimize leakage and thermal leakage. The F shell is basically an E shell folded in half.

Kettle units are used when vaporizing most of the shell-side flow. The large portion of the shell allows for the escape of the vapor and disengagement of the liquid from the flooded bundle. There are other reboiler styles, such as the thermosiphon style, which may be horizontal or vertical. There are some styles that are inserted into process columns to provide partial vaporization. Usually, a small shell section and the stationary end are provided with the "stabbed-in" bundle.

The G, H, J and X are used for special applications and as a method for keeping velocities low. The X shell is

also used in condensing applications.

Thermal factors. The purpose of a shell-and-tube heat exchanger is to transfer heat. There are many unknown factors associated with fluid flow, baffling, fluid properties and temperatures. The cleanliness of the fluids also impacts the ability of the fluids to transfer heat. To help ensure successful operation in an environment with many unknowns, as well as to allow for the degradation of performance over time, recommended fouling factors are provided. TEMA provides a list of recommended fouling factors for a wide variety of fluids. These fouling factors are resistances (to fouling) added to the estimated resistance when clean. In many situations, the fouling factors can result in substantial reductions in heat transfer rates. This can mean an increase in surface and size.

Use of fouling factors is recommended, but end users should provide guidance in the request for purchase that allows design engineers to include them. End users know the operating fluids and fouling conditions the best.

An extensive collection of good practices and checklists are included in the annex sections of API 660.

It is important to make sure that the fluids penetrate into a tube bundle properly for successful operation. TEMA provides guidelines for ensuring that damage to the bundle from high velocities in the inlet region do not result in concerns of erosion, vibration or high velocity impingement. Impingement plate, rods and nozzle sizing are factors that are specifically addressed in all of the standards discussed here.

Due to the number of flow configurations, shell designs and the degree to which the temperatures in the bundle have co-current flow components, charts with correction factors for the log-mean temperature difference (LMTD) for a number of equipment configurations are also provided.

Flexible shell elements and FEA. TEMA focuses substantial attention on expansion joints in fixed-tubesheet heat exchangers. It provides a method for providing reproducible results independent of the program or platform used to perform the analysis. Finite element analysis (FEA) is used for the flexible shell element (FSE) design. Figure 3 shows a large exchanger designed with FEA using the FSE approach.

ASME has moved toward making the tubesheet a BPVC-designed element using its unfired heat exchanger (UHX) section. For some exchangers, the design lies outside the scope of UHX. In such situations, it is recommended to consult good design practice and perform FEA on the tubesheet.

API Standard 660

The API 660 Standard for shell-and-tube heat exchangers is a tight, focused standard that requires a savvy and experienced end user, working with a manufacturer who understands and has worked extensively with user and process standards to achieve a highly reliable exchanger. It will result in a more costly heat exchanger, but one that will presumably be more reliable. The additional cost, however, may be small compared to the costs of loss of availability from tube failures, cross-contamination and in situations which the fluids are a potential safety concern. This is especially true when compared to the cost of an entire project.

An extensive collection of good practices and checklists are included in the annex sections of API 660. These are very useful and provide guidance on some of the more specific issues associated with petroleum-refinery operations.

API 660 has a process focus. It is not a manufacturers' standard, but rather an end-user standard. As such, it hosts more extensive requirements for the manufacturer, particularly with regard to quality and fabrication documentation for the equipment.

API 660 is used extensively in petroleum-refinery applications and includes drawing and information requirements. In addition to its refinery focus, the standard also targets chemical and LNG (liquefied natural gas) plants.

API 660 references TEMA as a base standard. In particular, TEMA R standards are incorporated. In addition, API 660 references ASME, EJMA (Expansion Joint Manufacturers Association) and NACE (National Association of Corrosion Engineers) standards.

While all the standards discussed here provide a list of issues that the end-user should address, API 660 provides the most complete set. It also provides a list of information that should be provided along with a proposal. This proposal information includes specification sheets and detailed information on the design and materials of construction.

After a contract award, API 660 recommends extensive drawing and document submittals. The drawings to be submitted provide end users with information that can be useful

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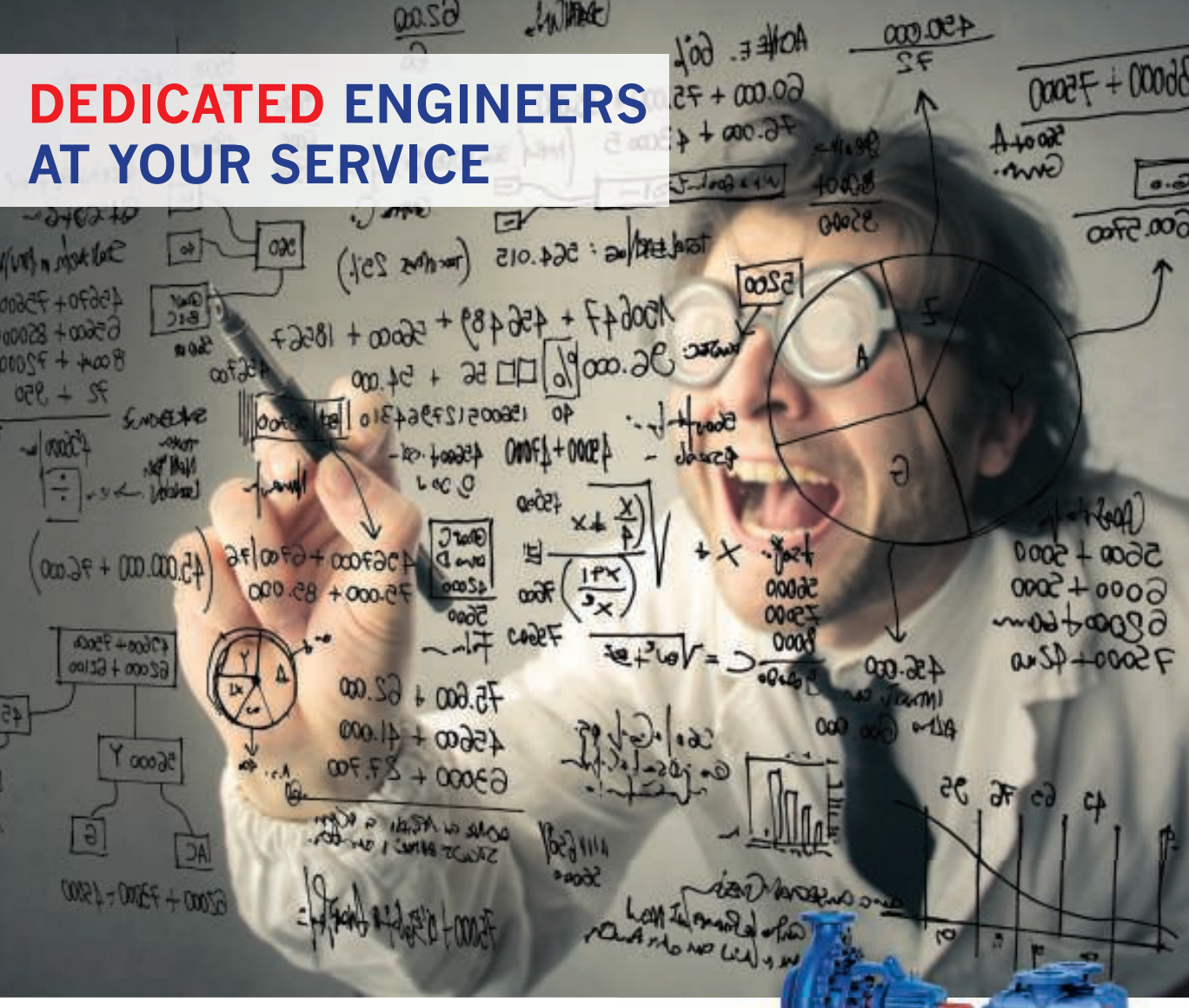

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for future maintenance and rebuilding.

Spare parts are also specifically addressed by API 660. Since many plants maintain their own equipment, spare tube plugs and gaskets can be important parts of the shipment.

Quality assurance documentation requirements are also provided. Documentation, such as material certifications, heat treatment and the types of NDE (non-destructive examination), can be important if failures occur. Such documentation can provide assistance in diagnosing problems.

Since API 660 is a refinery standard, it deals with a wide variety of fluids. It recognizes the need to reference NACE standards for addressing corrosion issues, such as wet hydrogen sulfide.

With the emphasis on the corrosiveness of the fluids, it is often desirable to have carbon steel clad with corrosion-resistant alloys. API 660 provides some guidelines in the use of the cladding material. This cladding can be used for tubesheets and other pressure-boundary components.

For end-users focused on specification, there is also a substantial amount of information in API 660 on reporting requirements. These requirements include welding details and procedures. The extent to which the reporting goes back to the end user is greater in API 660 than in most other relevant standards. Many of the fabrication procedures used by the manufacturers are referenced for review and approval. Such review and approval requires a certain level of expertise by the end user in order to assume responsibility over performance and reliability.

The full review of the mechanical calculations by the end user is similar to that in the ASME requirements. The primary difference is that the manufacturers' third-party authorized inspection agency (AIA) only reviews the calculations to ensure conformance with the ASME requirements and does not look at design limitations that may be imposed by other standards or specifications. The AIA does not check that the design meets API, HEI or TEMA standards or the specifications used when the units were purchased. This would also include nozzle loads and support loads that may be required by the standards or by the user specification.

API 660 has several pages dedicated to inspection and testing. This includes extensive

quality control requirements. Many of the requirements are options in the ASME BPVC but are selected by the customer. In general, the requirements are good design practices.

Requiring all Category A and B welds (defined at the beginning of the standard) to be full penetration and internal welds that all ground-flush to the shell ID is good practice, but may increase the cost. The strength welding of the tubejoint requirements are also good practice, and the standard allows for the user to accept other high-integrity ASME allowable tubejoint welds, such as explosive bonding (as referenced in TEMA).

There are also other areas where additional costs will accrue to the customer. The need for expertise in the calculation and procedure evaluation can be significant. Additional thicknesses on the tubesheets, flanges and other pressure-boundary components can also add cost. Reducing the use of reinforcement pads may also increase the cost of the heat exchanger.

The use of hydraulic stud tensioning for bolting 2-in. and larger components may also impact cost on larger and higher-pressure heat exchangers. It should be noted that the end user of a larger plant will most likely have such tensioning equipment, and a 2-in. bolt may provide a slightly smaller flange.

There are also adjustments to the girth flange designs. The cost added for the flange and gaskets can be significant.

HEI Standards for Shell-and-Tube Heat Exchangers

The HEI Standards for Shell-and-Tube Heat Exchangers (HEI) is a standard developed to address the needs of other exchangers used in power generation and similar industrial operations. Like TEMA, it is a manufacturers' standard. While the HEI Standard covers much of the same ground as the TEMA Standards, it has additional information on heat-exchanger surface protection. It also provides for the ability to evaluate different proposals within the context of a published pressure-drop calculation.

Shell-and-tube heat exchangers found in the power-generation and affiliated industries can vary significantly in size and complexity. Everything from liquid metal sodium-loop units and nuclear-fuel pool coolers to small lubrication-oil coolers are included in the HEI standard. HEI also maintains a useful set of technical briefs on its website. Some tubing vendors provide additional details on questions of material of construction.

HEI provides a more specific set of performance and design standards, as well as calculations on hydraulic performance. The scope of the heat exchangers is less inclusive than TEMA. In evaluating flow-induced vibration, TEMA provides a well-established and extensive approach. HEI's approach is not as extensive, but is certainly adequate. Most criteria are evaluated by computer programs.

The HEI Standard complements the complete set of HEI standards, including the Feedwater Heater Standard and Steam Surface Condenser Standard. Feedwater heater units can operate from a vacuum to supercritical pressures. Steam surface condensers are very large and operate at high vacuum.

Complex large one-, two- and three-zone feedwater heaters in vacuum up to ultra-critical applications (6,000 psi) are also covered in the Feedwater Heater Standard. The main steam surface condensers are covered in the HEI Standard of the same name. These units operate at high vacuum and there are additional standards in HEI covering the vacuum equipment as well. At times, these standards may help provide guidance on shell-and-tube heat exchangers that may be outside the limits of TEMA, API or even ASME BPVC.

There are similarities and crossovers between the HEI and TEMA. The HEI Standard incorporates a unique nomenclature set that is a bit more descriptive, but also more complex. While HEI is more complete in the design equations, it is also more limited in its discussion of heat-exchange requirements. Much of the services covered in HEI are related to water and steam, which do not carry the same corrosion issues as

those found in fluids addressed in API 660. However, the mechanical issues may be more extreme, due to the large pressure and temperature differences in their operation.

HEI is also used as a requirement in critical services, such as nuclear-fuel pool coolers and as such, can encompass portions of the ASME BPVC that are outside other standards. The standard includes ASME Section III, Division 1 Class 1, 2 or 3, as well as Section VIII Division 1 or 2 heat exchangers.

In the context of shell-and-tube applications, HEI provides additional information for customers to communicate to the manufacturer. Nozzle sizing in HEI is an important issue and is addressed specifically. In this regard, the inlet area and impingement protection is well defined and is similar to the TEMA recommended good practices. Relief-valve sizing is also directly addressed in HEI, and there is a section on heat exchanger protection that includes cathodic protection, painting and in-service inspection.

A high level of understanding of the codes and standards, along with engineering, can result in cost savings and increased efficiency for the end unit.

ASME BPVC

In the context of shell-and-tube heat exchangers, the ASME BPVC is usually employed to ensure that the design and manufacture of the physical components of the heat exchanger are designed and built to provide a mechanically safe unit. The BPVC provides for standard calculations to determine the minimum thicknesses of the pressure-retaining envelopes. Adherence to the BPVC is very important in the insurance of the plant that the exchanger is servicing.

The BPVC has a number of sections covering the design and fabrication of the various pressure parts of the shell-and-tube heat exchanger. Section I of the BPVC covers power boilers, Section III covers nuclear components, and Section XII covers transport tanks. Section IX covers welding. The section most often used in the context of shell-and-tube heat exchangers is Section VIII Division 1, which covers unfired pressure vessels.

This code provides the allowable material stresses for most materials for design purposes. The BPVC relies heavily on voluntary consensus standards developed by ASTM International (West Conshohocken, Pa.; www.astm.org) for establishing tests necessary to vet the integrity of the materials.

International boiler codes, such as the Japanese MHLW, European Standard (PED), Malaysia (DOSH) or Chinese SQL License, may have similar requirements or equivalence to ASME BPVC.

In general, equipment manufacturers provide quotations that must meet a user's thermal and quality requirements by providing the necessary heat-transfer surface in a pressure boundary. The design must be in accordance with the rules and criteria established by the ASME BPVC. The various flanges need to be designed and fabricated according to the calculations in the BPVC. The tubesheet(s) also needs to be designed in accordance with the BPVC unfired heat exchanger criteria. The shells and channels are often of welded construction, and the thicknesses, weld design, NDE and heat treatment need to be performed in accordance with the BPVC.

The fabrication and welding of shell-and-tube heat exchangers need to be in accordance with the BPVC. This means all the welding needs to be completed according to certified procedures. The materials and processes for the welding need to be in accordance with the BPVC. To ensure that these requirements are met, an authorized inspection agency is employed to provide third-party certification that the design and fabrication have met the requirements. A vessel that meets the BPVC is affixed with a stamp that provides the design temperature and pressure, along with a registration number from the National Board of Boiler and Pressure Vessel Inspectors (National Board). Such certification is often a requirement by those who insure the plant. It is also required by law in most U.S. states. The ASME at its base is a safety code.

The BPVC does not guarantee that the unit will meet the heat-exchange requirements. It ensures the vessel will not create a safety issue if operated in accordance with the specification. It does not guarantee that the materials will not fail from corrosion. The choice of materials for corrosion resistance is the user's responsibility, since they best understand the corrosion potential of the fluids. The BPVC cannot guarantee that the vessel supports and nozzles will take unspecified loads imposed.

When using the BPVC for shell-and-tube exchangers, the UHX requirements for tubesheet design have been incorporated. There are number of limitations to UHX, such as the percentage of the tubefield that

is tubed. In such situations, UHX references back to section U2(g), which is basically a fallback for the design engineer to use good practices. FEA is normally used to satisfy the UHX requirements.

Final recommendations

When an engineer is either buying heat exchangers for a new plant or specifying a replacement shell-and-tube exchanger to meet new process conditions, the starting point is choosing the base-level standards for the manufacture of the exchanger. Once the standards are selected, they must be reviewed to ensure that purchasers are confident that they can respond to the manufacturer in its efforts to meet the requirements.

The manufacturer must be specific with the customer on the information they will provide. They also need to support the user with appropriate options in materials and designs, which may provide additional lifetime or cost savings. In addition, they may meet operational limits, such as off-load or cyclic designs, that may not have been specified. Manufacturers should be considered as resources in this process.

The most reliable and efficient units are built when the user accurately communicates the needs of the end user and selects a manufacturer with a high level of engineering expertise who properly utilizes and applies the codes and standards referenced in the user specification. A high level of understanding of the codes and standards, along with engineering, can result in cost savings and increased efficiency for the end unit. ■

Edited by Scott Jenkins

Author

Thomas Muldoon is the president of American Exchanger Services Inc. (1950 Innovation Way, Hartford, WI 53027; Phone: 414-321-8003; Email: tom@amexservices.com; website: www.amexservices.com). Muldoon has been providing consulting services for heat exchanger operation since 1985, and established American Exchanger Services to provide field and shop services, and manufacturing of heat-transfer equipment for the power generation, process, chemical and paper industries. Muldoon has authored numerous ASME technical papers on feedwater heaters and condensers, and has presented additional papers at several EPRI (Electric Power Research Institute) Symposiums on High Pressure Feedwater Heaters and Joint Power Generation Conferences. He has also hosted webinars on Condenser Design and on several occasions, he has been a guest instructor at the EPRI Seminar on Feedwater Heaters. Muldoon holds a bachelor's degree from Marquette University and an MBA from the University of Wisconsin-Oshkosh. He is an ASME fellow.

Special Flange Joints Used in Floating-Head Shell-and-Tube Heat Exchangers

Single-pass, floating-head heat exchangers are common in certain process operations, but they often use flange joints that are not covered in existing design codes. Design details, advantages and disadvantages of the different options are discussed here

Pankaj K. Singla
Fluor Daniel India Pvt. Ltd.

IN BRIEF

Shell-and-tube heat exchangers are an essential element of petroleum refineries, as well as petrochemical and chemical plants. Shell-and-tube heat exchangers can be broadly classified into three types, according to TEMA (Tubular Exchanger Manufacturer's Association; Tarrytown, N.Y.; www.tema.org) construction classifications (see Part 1, p. 36). The three types are fixed tubesheet, U-tube and floating-head type. The floating-head type (S or T type) is widely used in petroleum refineries to accommodate fouling service and to allow differential thermal expansion between the shell side and the tube side of the exchanger that results from differences in fluid temperatures. Further, due to limitations in tube-side pressure drop, single-tube-pass floating-head heat exchangers are used. This subclass of shell-and-tube heat exchangers has an internal expansion bellow at the connection between the floating-head nozzle and the tailpipe.

No currently established design code or industrial standard covers the special flanged joints used for the single-pass floating head nozzle/tailpipe connection with expansion bellow. This article discusses construction details and configurations for this type of heat exchanger.

Single-pass, floating head

Petroleum refineries and chemical processing plants often encounter dirty fluid for both the shell side and the tube side of heat exchangers. Floating-head heat exchangers are the best solution for applications with dirty service on both sides. The allowable pressure drop for the shell side and tube side also plays a major role in finalizing the configuration of heat exchanger. When the tube-side allowable pressure drop is considerably low, and fluid cannot be put in the shell side, a floating-head heat exchanger with a single-tube pass is recommended.

The tube-side allowable pressure drop becomes the limiting factor in determining the length and number of tubes, and the shell-side pressure drop is maximized within that size by a baffle arrangement that will achieve the necessary performance.

Single-pass, floating-head heat exchangers are essentially fitted with an internal thin expansion bellow at the nozzle-tailpipe connection coming out of the floating head to accomodate the thermal expansion of the bundle. The configuration is not common in industry and the construction details vary based on the fabricator's experience, the client's preferences and also based on guidelines from the engineering, procurement and construction (EPC) expert. Floating head tailpipes assembling expansion joint shall be provided with the necessary lugs or support plates and retaining/limiting rods, which may also act as guide bars.

The mechanical detailing of single-pass, floating-head heat exchangers is not covered by any established design code or standard practice, so mechanical design and fabrica-

Figure 1A

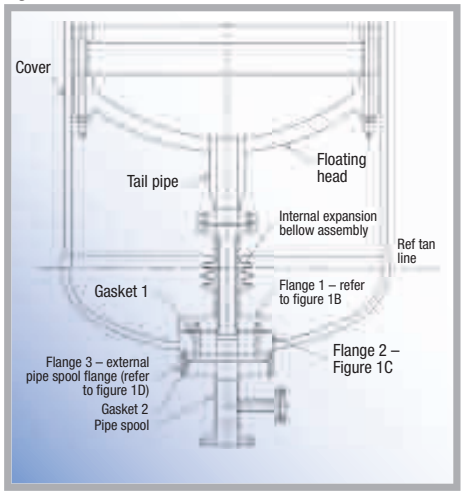


Figure 1B

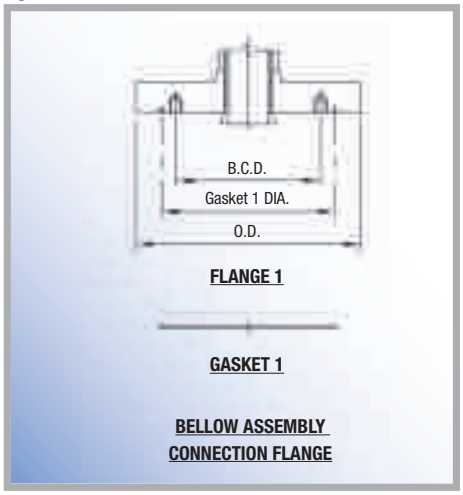


FIGURE 1. The figures shown here represent configuration 1 for special flange joints in a single-pass, floating-head shell-and-tube heat exchanger

Figure 1C

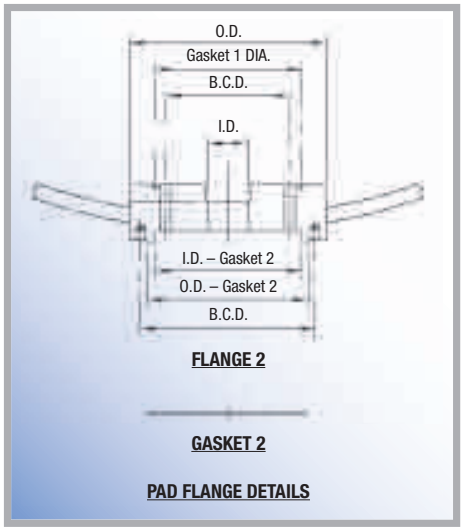
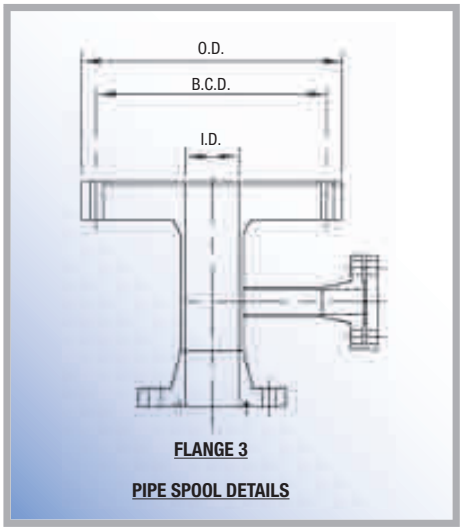


Figure 1D



tion of heat exchangers using these designs are very challenging for detailed-engineering contractors and vendors alike. The cost of the exchanger is higher due to the non-conventional details and design approaches. Process and thermal design engineers may not realize the potential complications associated with this type of heat exchangers when specifying such exchangers at the onset of a project. But during detailed engineering, fabrication, operation and maintenance, heat exchangers of this type continuously pose challenges and can increase time and cost at every stage.

Discussed here are various types of configurations and construction details for special flange joints adopted in previous projects for this single-pass floating-head shell and tube heat exchangers. The three cases discussed here have been encountered in various projects, but there may be other combinations related to these that are also used industrially.

In the cases mentioned here, all other details, such as the front end, shell, tube bundle and floating head, are the same. Shell cover dimensions may vary according to the number of components or the parts forming the bellow assembly. Also, their dimensions are required to meet mechanical strength as per the applicable design code or standard (or the best mechanical judgment).

Configuration 1

Special flange joint configuration 1 has the tailpipe coming out of the floating head bolted to the expansion bellow assembly using standard welding-neck, raised face (WNRF) flanges (Figure 1A). The other end of expansion bellow is welded with a non-standard flange (Flange 1; Figure 1B). A ring-type gasket has been used outside the bolt circle


Swagelok

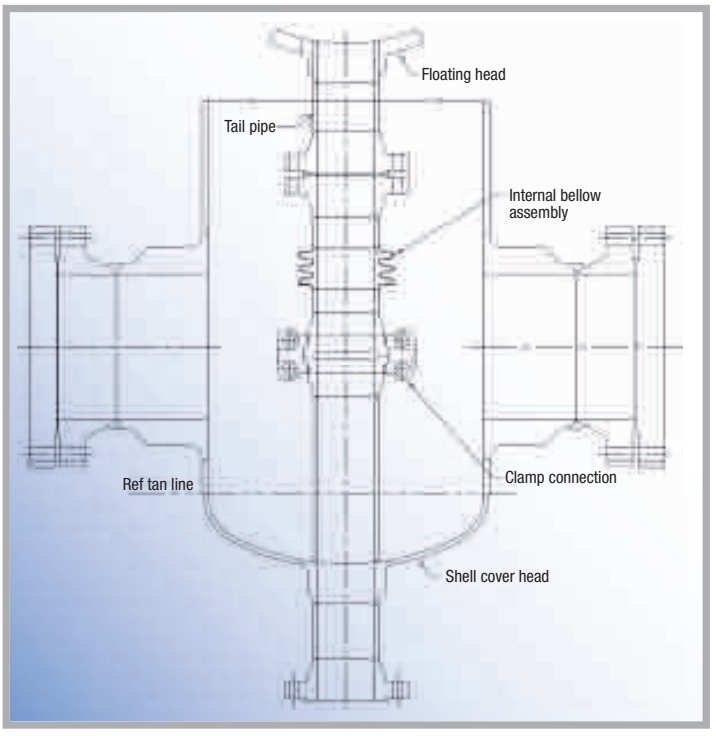


FIGURE 2. No non-standard designs are required for configuration 2 of the special flange joints, so it is less complex than the others

diameter (BCD) and the bolting arrangement is not through-bolt type. This flange is bolted to another non-standard flange (Flange 2; Figure 1C) which is welded to the shell cover.

An external piping spool or tube-side nozzle outside of the shell cover is bolted to a shell cover flange (Flange 2) with the help of another non-standard flange (Flange 3; Figure 1D), which is welded to the piping-spool nozzle neck. Flange 2 is bolted to Flange 3 using a set of bolts outside of the gasket with a not through-bolt-type arrangement.

Gasket 1 is used to seal the joint between Flange 1 and 2 to avoid intermixing between the shell-side and tube-side fluids.

The special flange (Flange 2) has gasketed joints on both sides, or faces. One side has a gasket outside the flange bolt's BCD and the other side has an inner gasket. Both sides' bolts are not through-bolt type.

This type of configuration has both advantages and disadvantages. Some of them are listed here.

Configuration 1 advantages:

- The bellow assembly is removable for inspection and replacement without cutting or repairing the shell cover flange or the floating-head tailpipe
- The inner set of bolts between Flanges 1 and 2 can be released from outside of the exchanger to detach the bellow assembly from the shell cover, helping to facilitate the assembly and disassembly of the bellow flanges
- No manway or inspection opening is required in the shell cover to access bellow's assembly for installation

Configuration 1 disadvantages:

- The design of Flange 2 is complex — it has two sets of bolts and gaskets on either side that must be designed according to best mechanical judgment, because this type of construction is not covered in any code or standard
- The bolts on Flange 1 are exposed to the tubeside fluid, which may cause corrosion of the bolts and crevice corrosion at the bolt-hole area on both Flanges 1 and 2, thus weakening the joint. This limitation can be avoided by employing an additional gasket placed inside of the bolts, so that there are two gaskets on either side of the bolts
- The bellows cannot be inspected without removing complete shell cover
- The gasketed joint between Flanges 1 and 2 is not accessible from outside of the shell cover. As a result, removing the shell cover is necessary for gasket replacement or other inspection

Configuration 2

This flange joint configuration is not complex, because there is no non-standard design involved (Figure 2). In this case also, the floating head tailpipe is directly bolted to the bellow assembly using standard WNRF flanges. The other side of bellow assembly has a Grayloc clamp connection for quick and easy opening of the joint. The remaining parts are welded to the shell cover. Two 20-in.-dia. manways are included to facilitate the removal of bolts from the Grayloc connection to detach the bellow assembly from the shell cover.

Some of the advantages and disadvantages for this type of flange configuration are listed here:

Configuration 2 advantages:

- All components and parts are standard, which results in a simple design for the bellow assembly and non-complex fabrication
- The simple design in this configuration helps allow the minimum number of gasketed joints in the bellow assembly and therefore helps limit intermixing of fluids or fluid leakage from either side
- The bellow assembly is removable for inspection and replacement without the need to cut or repairing the shell cover flange or the floating-head nozzle neck

Figure 3A

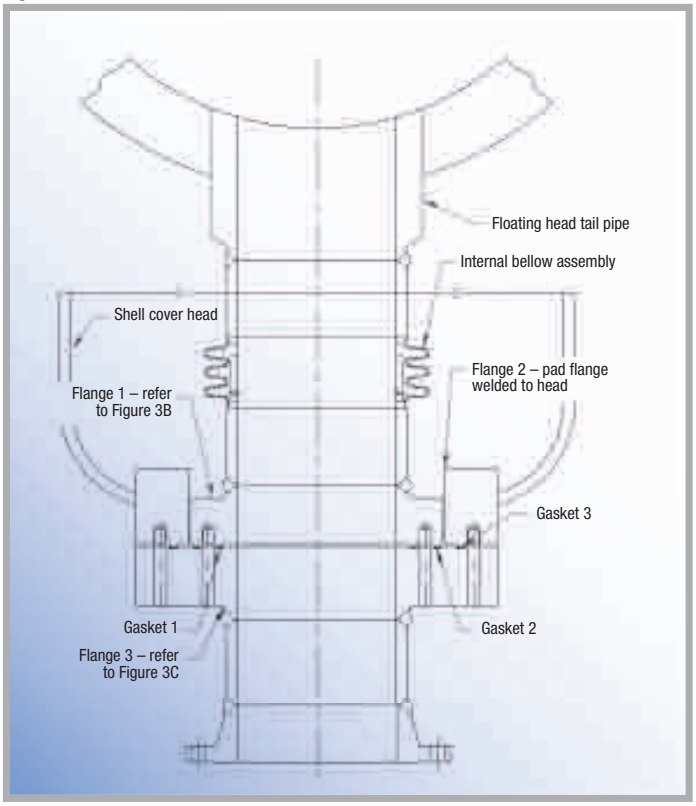
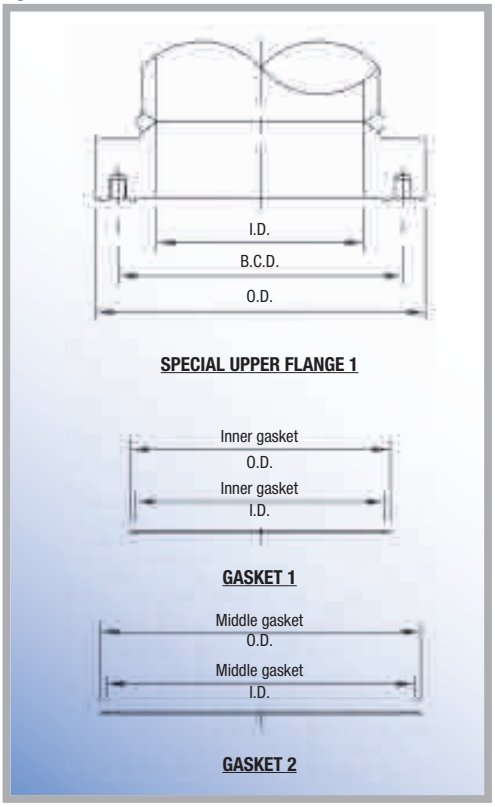


Figure 3B



Configuration 2 disadvantages:

- Two manways located at 180 deg from each other are required in the shell cover at the Grayloc-clamp assembly location to facilitate the assembly and dismantling of the bellow assembly from shell cover
- Because manways are required at the Grayloc clamp location, the shell cover, and the complete heat exchanger must be of longer length
- The gasketed joints between the floating-head tailpipe and the bellow flange and those at the Grayloc clamps are not accessible from outside of the shell cover, so removal of the shell cover is necessary for gasket replacement

Configuration 3

In this configuration, the floating-head tailpipe is welded with the expansion bellow assembly at one end (Figure 3A). The other end of the bellow assembly is welded to a non-standard flange (Flange 1). This special flange has two gaskets — both inside and outside of BCD and the bolting arrangement is not through-bolt type (Figure 3B).

A pad flange (Flange 2) is welded to the shell cover head. The external piping spool or tube-side nozzle outside of the shell cover is bolted to the bellow tailpipe flange (Flange 1) and shell cover flange (Flange 2), with the help of another non-standard flange (Flange 3), which is welded to the piping-spool nozzle neck (Figure 3C). Again, Flange 3 is a special kind of flange. It has three gaskets and two set of bolts (BCD). Both set of bolts have not through-bolt-type arrangement. The inner set of bolts is used to connect Flange 1 with two gaskets (the inner and outer gaskets). The outer set of bolts is used to bolt together the pad Flange 2 and the special Flange 3 with the gasket, inside of BCD. Flange 3 is exposed to both tube-side and shell-side fluids.

The shell cover and bellow tailpipe

Figure 3C

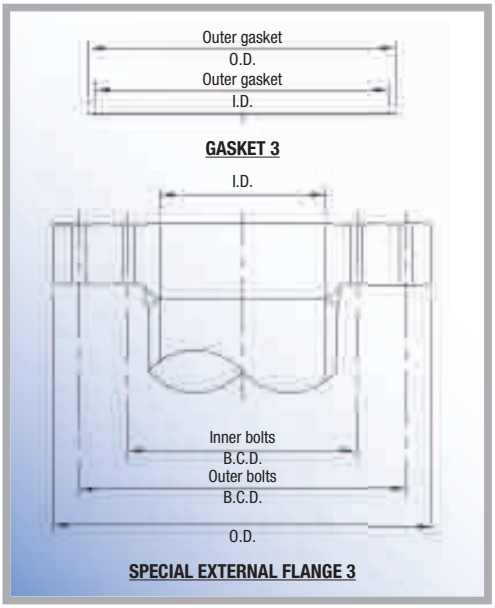


FIGURE 3. In configuration 3 of the special flange joint, the floating-head tailpipe is welded to the expansion bellow assemby at one end

are bolted separately to the external tailpipe spool, such that all gaskets in the flanged design are accessible from the exterior of the exchanger without removing the tube bundle.

Some of the advantages and disadvantages for this type of configuration are listed below:

Configuration 3 advantages:

- In this configuration, there is no gasketed joint inside the shell cover. This avoids the risk of intermixing of fluids inside the shell cover
- Gasket 1 is used to seal the tube-side fluid flow toward the inner set of bolts on Flange 1, and Gasket 2 is used to seal the shell-side fluid flow toward the inner set of bolts. This two-gasketed joint arrangement helps to avoid intermixing between the shell-side and tube-side fluids
- The inner set of bolts on Flange 1 can be released from outside the exchanger to detach the bellow assembly from shell cover

Configuration 3 of the flange joint has the advantage of having no gasketed joint inside the shell cover. This avoids intermixing of fluids inside the shell cover

- The outer set of bolts on Flange 3 can be released from outside the exchanger to detach the external piping spool from heat exchanger, allowing access to all three gaskets for inspection without removing the shell cover
- No manway or inspection opening is required in the shell cover to access the bellow's assembly for installation
- A relatively shorter shell cover is possible compared to the other two configurations described here.
- ***Configuration 3 disadvantages***
- With Configuration 3, the bellow assembly needs to be cut and re-welded for replacement
- The design of special Flange 1 is complex. It has two gaskets under different design conditions and one set of bolts
- The design of special Flange 3 is also complex. It has two sets of bolts and three gaskets. Both special flanges have to be designed according to best mechanical judgment, because this type of construction is not covered in any code or standard
- Bellow cannot be inspected without removing complete shell cover.

Challenges for special Flange 3

There are a host of challenges associated with finalizing the design of the special flange 3 in configuration 3. It is imperative to note that with this flange, the innermost gasket (Gasket 1) is exposed to tube-side design conditions, while middle gasket (Gasket 2) and outermost gasket (Gasket 3) are exposed to shell-side design conditions. The flange does not fit into any code-specific configuration, and finite-element analysis of such shapes with complex design conditions is nearly impossible. Manual calculations, by using modified formulas for flange design from an existing design code, can be one of way to complete mechanical strength calculations. Different users may adopt other ways to perform calculations based on their best mechanical judgment.

Major challenges for this flange design will be in finalizing the gasket-load reaction diameter "G" and the bolt circle diameter "C" for this calculation, because the three gaskets have three different values of "G" and the two sets of bolts give different lengths of lever arms to calculate moments in operating and gasket-seating conditions. For the gasket-seating condition, the minimum required bolt load can be easily calculated using all three gasket parameters.

Higher design temperature from both sides can be adopted as flange design temperature. Another challenge will be to calculate minimum required bolt load for the operating condition, because different portions of the flange are exposed to different design pressures.

After some iteration, engineers can arrive at a working design that is acceptable to local authorities and to the American Society of Mechanical Engineers, as applicable. ■

Edited by Scott Jenkins

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Author

Pankaj Kumar Singla is a mechanical design engineer for Fluor Daniel India Pvt. Ltd. (6th Floor, Infinity Tower B, Cyber City, DLF City Phase II, Gurgaon 122 002, Haryana, India; Email: pankajsingla99@gmail.com; Phone: +91-97164-14125). Singla has more than eight years of experience in detailed engineering of static equipment in the pre-bid phase, as well as front-end engineering design and detailed engineering for various oil and gas, petroleum refining and petrochemical industry projects. Prior to joining Fluor, Singla worked for Daelim Industrial Co. (South Korea) and Valdel E&C (India). He holds a B. Tech. degree from the Giani Zail Singh College of Engineering & Technology, Bathinda, Punjab, India.

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A Primer on Compressor Design

From initial conceptualization to final calculation, designing compressors requires not only engineering intuition and robust simulation tools, but also a bit of creativity

Valentine Moroz
SoftInWay, Inc.

IN BRIEF

FIGURE 1. While there are numerous compressor types frequently used in the process industries, centrifugal compressors are among the most ubiquitous

As technology has evolved, so has the refrigeration industry. What were once holes in the ground filled with ice and snow have transformed into the modern high-efficiency compression machinery we have become so familiar with today. However, as common as these devices have become, the design process remains a challenge. This is where a combination of scientific knowledge, experience and creative initiative comes into play. While there are, of course, several variations in terms of the application of each design step, the guidelines presented here could be applied not only to refrigeration compressors, but also to compressors used in many other processes and industries.

There are a number of steps to consider throughout the compressor design process, and each step has to relate back to the original design concept. Experience has shown that having a starting concept and an end goal in mind is imperative. Namely, before you can begin the process, you need to know where you are starting and where you want to end up. With this in mind, before we can even get started with preliminary design, blade profiling and analysis of computational fluid dynamics (CFD), it is important to take out a piece of paper and start brainstorming. Consideration of the different refrigeration technologies (cycles), is always a great place to start, so we can ensure we will design the best compressor for the application. The cycle will directly impact the rest of the compressor design decisions, so this is not a step that can be bypassed. This article's discussion begins with cyclic compression.

Cycle design and optimization

Cyclic refrigeration units are used for reducing and maintaining the temperature of a body below the general temperature of its surroundings. In a refrigerator, heat is pumped from a low-temperature heat source to high-temperature surroundings. According to the second law of thermodynamics, this process can only be performed with some aid of external work. The vapor-compression refrigeration cycle (which is a type of cyclic refrigeration) is used in most household refrigerators, as well as in many large industrial systems. The advantages of choosing this route are that the technology is mature, the costs are relatively low and the process has the capacity to be driven directly with electrical or mechanical energy.

For initial consideration of the compressor, we must perform calculations to determine the operating conditions and system function, the type of working fluids and the system size and requirements, as well as the economic analysis of the whole cycle. By completing these steps prior to beginning the preliminary design, we are establishing boundary conditions, performance requirements and geometric constraints for the compressor before committing to a design that may or may not be realistic.

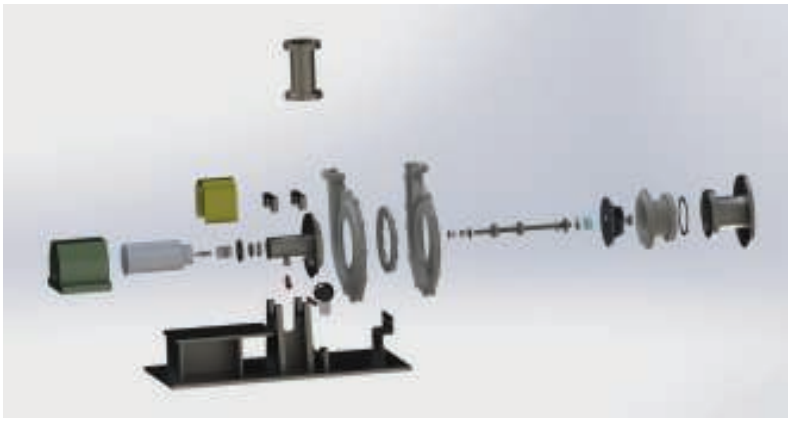

FIGURE 2. Centrifugal compressors include several critical internal components that cannot be ignored during the preliminary design phase

Next, we must determine the type of compressor we want to use for the refrigeration cycle. For the purposes of this article, we will focus on the centrifugal configuration (Figure 1). However, many other options exist, including reciprocating, scroll, helical and rotary compressors.

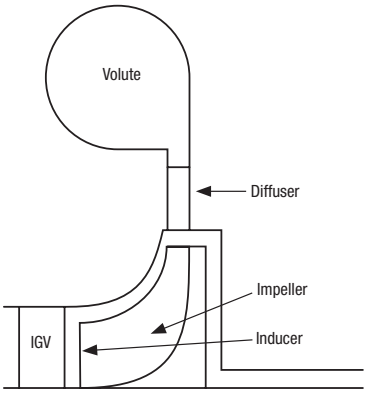

FIGURE 3. The many internal components of compressors, including the diffuser, impeller and inlet guide vane (IGV) must be considered in order to ensure a robust design

FIGURE 4. Blade profiling is an essential design step in confirming the operability of a proposed compressor geometry. This image shows a completed compressor blade for radial machinery after streamline analysis and CFD analysis has occurred

To elaborate on the output from cycle calculations, we also need to know several specific data points for the proposed compressor, including the required pressure ratio, discharge pressure, volumetric flowrate of the refrigerant, application requirements and the assumed required economics. At this stage, the procedure feels much more like science than art.

Next, the designers need to decide whether they want to design a compressor using an existing similar design (requiring them to scale up or down and optimize the design) or to start from scratch with something completely new. For the purposes of this article, let's focus on a new design. Now that these decisions have been made, let's revisit that piece of paper from the brainstorming session and launch into the design process to make the project a reality.

Preliminary design

Once brainstorming is complete and the technical specifications have been defined, preliminary designs and feasibility studies can begin. First, it is recommended that the engineer start by listing all of the constraints determined in the brainstorming step. From there, a novel approach to preliminary design is to use an inverse-design method of problem solving. Specifically, what this means is that we want to consider the specific performance of a compressor and then determine the best geometry to achieve this performance by using software and solver tools. Here, it is important to begin considering the internal components of the compressor (Figure 2). The primary components of a centrifugal compressor stage are the impeller, inducer, diffuser (vane or vaneless) and volute (Figure 3). The impeller functions to increase the fluid pressure, and the diffuser further increases the fluid pressure by utilizing the kinetic energy of the flow, which is available downstream of the impeller. The volute is used for flow collection and for directing the fluid to the pipe. The inlet guide vane (IGV) provides mass flowrate control. Fundamentally, since the total enthalpy and pressure rise of the compressor stage occurs at the impeller, the impeller's performance and loss prediction are among the most important aspects of centrifugal compressor design and analysis.

To run an inverse-task exploratory approach of preliminary design, and further explore the design space, we must consider different types of impellers and which to use. Some of the options to consider include whether the impeller is shrouded or unshrouded, whether or not an inducer is present on the impeller and whether a forward or backswept impeller blade is used at the outlet. Other options include splitter blades, types of diffusers, IGV exit and so on. To arrive at the appropriate decision about which configuration to use, we must consider various losses that can exist during different modes of operation and applications, including friction, windage, leakage, recirculation and passage blockage. Once we are settled on the specific type of configuration we want to study, the simulations can begin.

Meanline and streamline design

After we have picked one or several potential geometries and designs, the next phase is to perform meanline and streamline (also sometimes called through-flow) calculations. To better explain this, if the cycle is zero dimensional (0-D) and the inverse task/preliminary design is one dimensional (1-D), then this is

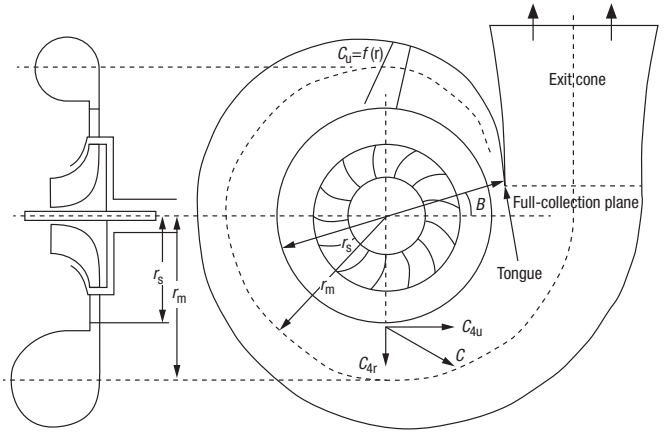

FIGURE 5. Considerations related to friction, flow velocity and circumferential variation are important when evaluating the design of a compressor's volute

considered a two-dimensional (2-D) design. The meanline approach is a 1-D calculation at the pitch (mean) line with extrapolation of the flow properties at the hub and shroud. The streamline approach is a 2-D calculation accounting for real blade angles at each spanwise location, and is especially useful for longer blades. Here, we are considering the actual geometries (profiles) we evaluated previously and performing more precise calculations to see the real performance of these compressors, as well as what that performance will be at different operating conditions. Although turbomachinery is typically designed for a set of specific operating conditions, it is also a good idea to consider the performance characteristics in "off-design" conditions. Just like the prior ones, this step is quite important, because these simulation calculations are significantly faster to run now, as opposed to doing so in the later CFD step. By generating a full performance map with a 1-D tool, it is possible to estimate working range and choke or surge margin early on with acceptable accuracy.

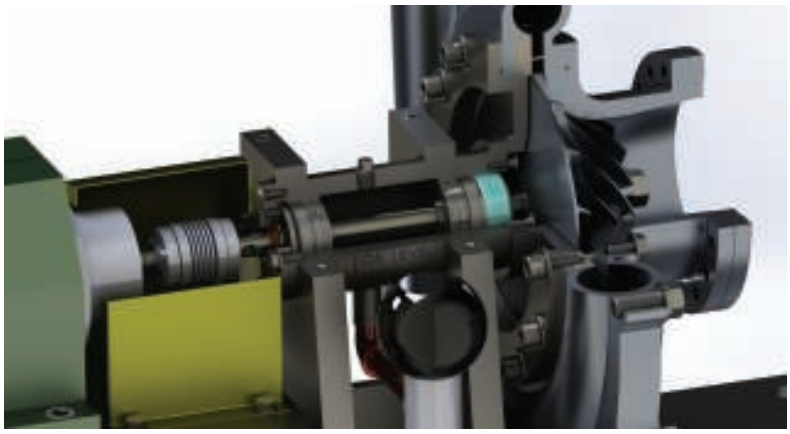

FIGURE 6. A robust compressor-design software evaluates the performance and characteristics of journal bearings, as well as many other operational considerations

Software best practice. Designing a compressor is certainly not a simple task. While it can be appealing to have a range of different software tools each specialized for a different function, this is typically not the best course of action. Going through each of these steps can be extremely tricky when you use a number of different software design tools, since, not only is there the time commitment of figuring out how each works, there is also the potential for error associated with reentering data at each design step, as well as the struggle of ensuring

that each platform integrates with one another. For this reason, it is typically best to stick with one or two integrated platforms that can accomplish what is needed to complete the given design project.

Blade design and profiling

Now that we have a geometry and are comfortable with its assumed performance characteristics from the previous steps, the next activities will be profiling and blade optimization. During the profiling of the plain sections, we need to control the quality of the flow in the channel to achieve results with minimal profile losses and reasonable distribution of thermodynamic (pressure) and kinematic (velocity) parameters along the channel.

The typical and most applicable mechanism of blade-shape definition for radial machines is the angle distribution along the meridianal length of the blade channel (Figure 4). Here, the major objective is to determine which blade shape is optimal, and whether we obtain it with our geometry. The answer lies more in creativity than science. The understanding of the flow particularities, and even an imagination of the fluid behavior, should be called into play. This can even be called an engineering art. Further, we validate our blade-building skill with the 2-D/3-D calculating methods — full streamline analysis and 2-D/3-D CFD. Usually, this is an iterative process.

Volute design

A volute, in this case, is a casing that receives the working fluid coming out of the impeller. The volute typically looks like a curved funnel, as seen in Figure 5. The main objective of volute design is to define the circumferential variation of the mean radius and cross-sectional area. The different types of volutes are as follows:

1. External, with an outer diameter higher than the diffuser discharge diameter
2. Internal, with the volute outer diameter equal to the diffuser outlet diameter and the inner diameter lower than the diffuser exit
3. Intermediate (somewhere in the middle of option 1 and 2)

Volutes may also be classified by the shape change across the circumference (constant external diameter, constant internal diameter and constant mean diameter).

Once we have considered the type of volute, the next main objective becomes to define the circumferential variation of the mean ratios and the cross-sectional area. There are two main methods of doing this, described below.

Simple area schedule (SAS). A desired flow velocity at the scroll discharge is used to set the area at the full-collection plane. Then the volute area is allowed to vary linearly with the polar angle, 0 deg.

Area distribution. Establish an area distribution from the principles of conservation of mass and angular momentum.

When considering volute designs, we must also consider losses, which include incidence losses and losses

related to flow turn in the volute, such as friction, mixing losses and so on.

Computational fluid dynamics

CFD calculations are an integral part of centrifugal compressor design and are an important final step for broad modeling and simulation of flow, heat transfer and turbulence. The main objectives of 3-D CFD calculations are to evaluate the quality of the flow path, compare the results of 3-D CFD calculations and the meanline and streamline calculations' experimental data, and check for the presence of flow separation, supersonic shocks and the effects of 3-D blade design.

In most CFD codes, the main aspects include a preprocessor, which is used for mesh construction, definition of fluid properties of the appropriate boundary conditions, a solver and a postprocessor for analysis and display of results. Typically, the process starts with loading the data into the CFD software, with given boundary conditions, geometry shape and so on. Next, the engineer needs to create and define the mesh. Mesh generation involves the computational domain where the engineer solves a set of equations (specifically Navier-Stokes equations) to obtain an appropriate mesh (grid). Finally, it is time to set up the solver and monitor for completion. Once the solutions are presented, the engineer must review the results, and adjust the models to make sure that everything is reasonable, and of course, if issues arise, revisit the geometry in the profiling tool to make the appropriate changes.

Finite element analysis

Finite element analysis (FEA) is another important step of centrifugal compressor design — especially so for refrigeration compressor applications, as those may involve working with challenging fluids. The objective of this type of analysis is to explore how the compressor (or anything for that matter) would perform under "stress" operation. Engineers typically want to perform static, modal and harmonic analysis. When undesired stresses are discovered in the compressor (usually on the impeller), the engineer goes back to the profiling step and iterates the design to minimize these performance characteristics. Although seemingly straightforward, this step can result in serious time and monetary losses if not carried out correctly.

Rotor dynamics

Rotors and bearings are the most critical components of any rotating machinery, including centrifugal compressors. Rotor lifetime and reliability depend, first of all, on the level of rotor vibrations. In order to meet the highest requirements of reliability, each step of rotor design for a centrifugal compressor should be based on accurate rotor-dynamics predictions.

Recognizing all these points, we cannot forget to perform rotor dynamics analysis during the process of compressor development. Using a given design software, we can perform the full-scope rotor dynamics analyses required by widely used standards. To guarantee safe centrifugal compressor dynamic operation, we want to perform static deflection analysis, critical speed and map analysis, stability analysis, unbalancing response, model torsional analysis and time-transient torsional analysis. Another useful tool here is a Campbell diagram, which shows the frequency versus the rotation speed of a shaft, allowing for analysis of these two factors to determine the functionality of a given design.

When undesired stresses are discovered in the compressor (usually on the impeller), the engineer goes back to the profiling step and iterates the design to minimize these performance characteristics

Coupled to this process is the estimation of bearing workability. Often, using a software module (Figure 6) packed with mechanical and hydrodynamic characteristics for various types of journal bearings (including oil, gas-foil and ball-bearings), stiffness and damping characteristics is best, because you can also simulate the thrust.

Closing thoughts

Using refrigeration compression as an example, it is clear that quite a lot of thought goes into compressor design before any engineering work can take place. After you have brainstormed and decided on the type of compressor you wish to design and what you need it to do (where you are and where you're going), the work really kicks into full gear. Preliminary design must be conducted, followed by meanline and streamline analysis, volute design, CFD, FEA and finally rotor dynamics. While this can all appear overwhelming at first, compressor design is a skill that can be perfected through the means of science, art and practice. Rome certainly wasn't built in a day, and neither is your compressor. So once you have the logistics figured out, patience is key. Combining your own knowledge with the steps presented in this article, along with an integrated software platform and a team of enthusiastic colleagues, will put you well on your way to a successful compressor design. ■

Edited by Mary Page Bailey

Author

Valentine Moroz is the chief operating officer (COO) of SoftInWay Inc. (1500 District Avenue, Burlington, MA 01803; Phone: 1-781-685-4942; Email: valentine@softinway.com; Website: www.softinway.com). Moroz has been involved in turbomachinery for over 15 years, and has supported SoftInWay in the capacity of COO since 2009. In this role, he has been instrumental in growing the turbomachinery development and services business from his involvement in moderately sized design projects to engaging in complete turnkey product development, ranging from green-energy turbines to refrigeration compressors. His specialties include turbomachinery technologies, such as turbines, pumps and compressors. Additionally, his responsibilities include sales, marketing and finance for the SoftInWay Group of companies, as well as opening and staffing global offices in Switzerland, India and the U.S.

Advances in Pin Mill Technology

Improvements provide finer grinding at lower energy costs compared to air-swept classifying mills that have long reigned supreme in particle-size-reduction efforts

Sam Rajkovich
Sturtevant

For decades, the ultimate performance in fine mechanical milling performance has been provided by the air-swept classifying mill (ASCM). Perfectly suited to a broad range of non-abrasive milling applications, the air-swept classifying mill is a single machine used to carry out a two-step process. The process both reduces particle size and limits the output of particles using mechanical classification — only delivering those particles of a predetermined, easily controlled, fine size as the finished product exiting the mill. Historically, this technology has offered performance advantages over other options, in terms of its ability to deliver highly controlled particle sizes for a broad range of applications, from powder coatings to paper fillers. Until recently, the air-swept classifying mill has been widely held as the gold standard in milling technology.

Today, those processors seeking to upgrade or purchase new milling equipment have several different types of impact milling technologies to select from. The pin mill is one option that has seen major advancements over the last decade, enabling performance that rivals that of the air-swept classifying mill. Until recently, significant differences between air-swept classifying mills and pin mills were obvious. In general, air-swept classifying mills provided the ultimate milling performance, but also carried a large capital investment, as they required the purchase of a baghouse filter (to separate the milled material from the air stream), a high-static-pressure blower and auxiliaries. These auxiliaries and the operation of the mill increased the cost per ton of material processed by the mill, and contributed to a more sizable ongoing investment.

FIGURE 1. The air-swept classifier mill carries out size reduction and classification in a single process, and particle size can be controlled by adjusting such variables as airflow rate, feed rate, classifier speed and residence time in the chamber.

Historically, while pin mills have always used less energy, been simpler to operate, and been more economical overall, they were not as effective in terms of their ability to reach the same levels of fine-particle size. A primary goal of mill manufacturers over the last decade has been to close this gap in particle-size capabilities, to take advantage of the improvement in cost-per-ton figures that a pin mill can yield. To help readers better understand a comparison of the economics, a brief introduction to each of these two technologies is presented below.

Air-swept classifying mills

Air-swept classifying mills (Figure 1) are impact mills that can grind materials into very fine powders. The products range in size from about 100 µm (the diameter of a human hair), down to 5 µm (the diameter of a red blood cell). Despite being relatively costly to operate and requiring an experienced operator, users throughout the chemical process industries (CPI) have tended to gravitate toward them, thanks to several unique features beyond fineness. Such desirable attributes include the following:

- The air-sweeping feature can cool materials
- These systems have the ability to hold and control particles through mechanical classification
- The design allows operators to remove oxygen from the process using inert gases, such as nitrogen or argon, thereby reducing the risk of spark or ignition
- Air-swept classifying mills can produce particles in small sizes that other mechanical mills cannot

How air-swept classifying mills work. Air-swept classifying mills perform both milling and air-classifying

FIGURE 2. Pin mills can be configured in many ways to suit the needs of the application (for instance, using vertical or horizontal shaft, pneumatic or gravity-feed options, varying materials of construction and pin configurations) and more

functions in a single step. As the inlet product comes into contact with a series of spinning impact blocks, the material is smashed into fine particles that pass through a cage of spinning blades called the air-classifying wheel. The wheel acts as a screen and only lets the particles that are small enough through. The larger particles remain in the mill for additional grinding. In its simplest form, fine particles exit the mill and are collected in a baghouse product collector. Particle size is adjusted by increasing or decreasing the classifier speed. Airflow rate and feed rate affect the residence time in the chamber, and the action of the sweeping air prevents heat buildup.

Types of air-swept classifying mills. Air-swept classifying mills vary by size, speed and air flow. Different systems use various impact elements, materials of construction, impact walls, impact area geometries and directions of material flow. These options are used in combination to produce smaller particles, or a product with greater uniformity, less contamination, or any such characteristics that may be deemed desirable for a particular application. Most manufacturers of air-swept classifying mills offer a standard industrial version and customized versions. Customization options typically include specific, duty-purpose innovations to suit individual markets.

One manufacturer offers a variant of the traditional air-swept classifying mill that is specifically designed for food ingredients. It presents material directly to the classifying wheel first, to reduce the energy used for grinding "on specification" material, and then uses hammer blocks to grind the material. The standard materials of construction change to stainless steel and the fasteners are changed to no-tool access (this feature has helped the design to gain U.S. Dept. of Agriculture (USDA) acceptance). Another manufacturer offers a variant that is specifically designed for grit reduction of low-density materials, such as carbon black. The feed stream is introduced below (rather than above) the rotor, and the mill incorporates an external coarse recycling system.

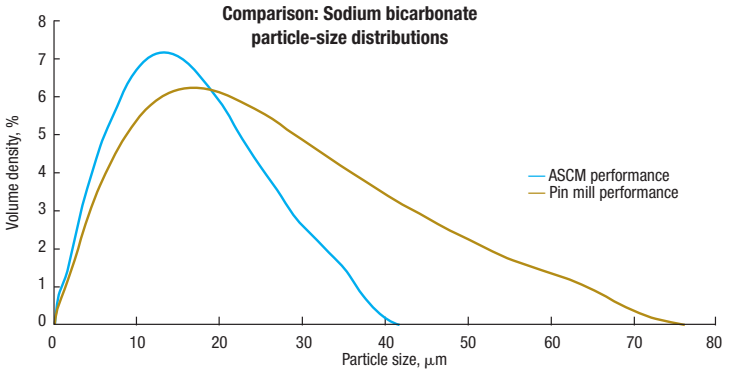

FIGURE 3. Shown here is a comparison of the particle-size distribution for a pin mill versus an air-classifying mill handling sodium bicarbonate. As shown, the pin mill was not able to achieve the same maximum fineness as the final product produced by the air-swept classifying mill

Pin mills

Modern impact pin mill technology. Pin mills use varying degrees of impact and agitation to process many types of materials. They perform a variety of functions, helping users to reduce the size of bulk solids, deagglomerate materials, break apart fibers in natural materials, densify, fluff, mix, blend, disperse and homogenize the product. They provide a range of speeds. Relatively slow mixing and blending typically has rotor speeds on the order of 6,800 ft/min; high-impact grinding may have speeds up to 36,000 ft/min. Today's designs are sealed to provide controlled atmospheres. Constructed from stainless steel, carbon steel, and many other materials, they are available for applications in the chemical process, food, pharmaceutical, grain milling and mineral industries.

How pin mills work. There are several types of pin mills, but all of them achieve the same end: producing homogeneous products. They work by introducing the feed product onto various spinning rotors with different configurations of pins or blocks that act as impactors. The number and orientation of the pins determines how material is processed, and the rotor speed determines the force of impact.

Size reduction results when materials flow through a maze of pins that have many interactions at higher speeds (Figure 2). Gentle handling, such as mixing and blending, happens at lower speeds so more of the energy can be efficiently directed into the product without degrading it. Individual pin mill designs feature different types of rotors and rotor diameters, varying types, numbers, and orientations of pins, different capacities, feed options and liners to produce different results.

FIGURE 4. In recent years, pin mills, such as this one milling trona, have become competititve with air-swept classifying mills on performance, but also can yield reduced capital, energy and operating costs

Types of pin mills

The type of pin mill to consider for an application depends on the size, density and type of product that is supplied and desired, and the environment the mill will be working in. Pin mills can be customized to fit with pressure-pneumatic or gravity-feed systems, and they can be constructed from different materials according to the application.

Horizontal and vertical pin mills. The name indicates the orientation of the rotor. Some applications have special requirements so they can only use one or the other. For instance, those that need a screen at the bottom require a vertical mill.

Centrifugal impact pin mills. These mills are used to reduce medium- to low-density materials to fine, uniform sizes of 50–325 mesh (300–44 microns, μm), for applications where low wear is critical. They are widely used in many low-wear markets, including food-product processing, such as corn fractionation, flours, starch densification, corn slurry, sugar and sweeteners, and semi-abrasive material applications, such as aluminum sulfate, fertilizer, gypsum, soda ash, tungsten and other powder de-agglomeration (including tungsten), talc, clay and kaolin.

Pin mill advances

Most pin mill advances are based on specific needs of certain applications. As noted above with duty-purpose air-swept classifying mills, pin mills are also customized to meet user requirements, with the resulting designs and configurations then integrated to produce

TABLE 1. OPERATING COST COMPARISON: PIN MILL VS. AIR-SWEPT CLASSIFIER MILL (SODIUM BICARBONATE FINE-CUT CAPACITY)

	Pin mill	Air-swept classifier mill
Fine-cut capacity	1,500 lb/h	1,500 lb/h
Exhaust fan	N/A	20 HP @ 460 V (15 kWh)
d10, d50, d90, µm	d10 = 2, d50 = 13, d90 = 48	d10 = 2, d50 = 9, d90 = 22
Resulting kWh used	18.35 kWh	51.84 kWh
Operating cost of 1,500 lb/h at $0.13/kWh	$2.39/h	$6.74/h

the desired products. Thanks to ongoing design and material improvements, pin mills are trending toward producing finer and finer cuts, now typically in the 30–300-µm range.

When manufacturers are able to combine a few of the features already discussed, an assemblage of key features can now be realized. For instance, a vertical-shaft pin mill that provides very fine particle distribution can now have low maintenance requirements, be cost-effective and simple to operate. A final comparison must be made on the tradeoff between the cost to operate in kilowatt hours and relative fineness of the same material, because a pin mill still cannot achieve the low, tight particle size distribution exactly like an air-swept classifying mill.

Comparing key attributes

To compare the energy usage, particle sizes, and operating cost of the two technologies, laboratory testing was carried out using a pin mill and an air-swept classifying mill. Both mills processed identical material with corresponding throughput settings. The simulation was based on an industrial fluegas-treatment application, where sodium bicarbonate would be used for dry sorbent injection. The resulting particle-size distributions and energy consumption were also observed so operating costs and performance could be compared between the two systems. The test was run under similar conditions and optimal horsepower settings. Each mill design is flexible and horsepower can be adjusted for every application. Table 1 summarizes results from a side-by-side comparison test, showing energy consumption per hour on a kilowatt (kW) basis.

Energy cost per hour to mill 1,500 lb/h was calculated using a utility cost of $0.13/kWh, by the following equations:

Horsepower formula (3-phase):

$$\frac{1.732(V)(Amps)(EFF)(PowerFactor)}{746} = \frac{\left(kW/HP\right)}{746} = HP \quad (1)$$

$$\frac{1.732(460V)(Amps)(0.9)(0.95)}{746}$$

Where:
EFF = Motor efficiency (typically expressed as percentage)

Conversion from HP to kW:

$$HP\left(\frac{0.746kW}{HP}\right) = kW \quad (2)$$

Cost to operate:

$$(kW \bullet h)\left(\frac{cost}{kW \bullet h}\right) = \$ \quad (3)$$

$$(kW \bullet h)\left(\frac{\$0.13}{kW \bullet h}\right) = \$$$

As demonstrated in the table, using $0.13 per kWh, a $5.78/ton savings is shown in this example. To understand the savings, consider a single-shift plant, assuming 8-hour days and 250 d/yr, the annual savings would be $8,700 using a pin mill versus an air-swept classifying mill.

However, observing the graph in Figure 3, it is also important to note that based on these results, the pin mill never achieved the maximum fineness that was possible with the air-swept classifying mill: 50% of the particles produced by the pin mill exceeded 13 µm, compared to 9 µm with the air-swept classifying mill; and 90% of particles from the pin mill passed 48 µm, versus only 22 µm for the air-swept classifying mill.

Regarding target fineness, the takeaway is that when fineness of 20 µm for 90% or more of the volume being processed is a key objective, pin mill technology may not be quite ready to handle the challenge. However, if there are allowances for particle size in the upper limits of the particle distribution, the pin mill performance is very close to that of the air-swept classifying mill. When looking at only the average of particles — the d50 value — fineness is almost identical.

In the past, pin mills (Figure 4) were only capable of producing top sizes down to 75 µm — the theoretical limit of fineness on a pin mill. Equally for an air-swept classifying mill, many believed the finest materials it could achieve were in the range of 20 µm. Today, the theoretical fineness in air-swept classifying mills is in the 5–10 µm range, with the practical limit being around 20 µm. Pin mills have achieved a practical range down to 40 µm, which is very similar to that of air-swept classifying mills so the gap is narrow.

For users who want narrow particle-size distributions, air-swept classifying mills do it well consistently, but advancements in pin mill technologies show that they are now able to produce comparable particle-size distributions, too. Although pin mills cannot do everything that air-swept classifying mills can, in some cases, the cost to operate the latter outweighs the benefits of milling performance. In these situations, the advancements in modern pin mill technologies can far outweigh the investment and cost to operate an air-swept classifying mill.

Understanding the trade-off between energy, fineness, and the convenience features of a modern pin mill relative to an air-swept classifying mill may be an important step in any plant's next design review. ■

Edited by Suzanne Shelley

Author

Sam Rajkovich is the vice president of sales & marketing of Sturtevant (348 Circuit Street, Hanover, MA 02339; Email: srajkovich@sturtevantinc.com; Phone: 781-829-6501; Website: www.sturtevantinc.com). A 15-year chemical and bulk solids veteran, Rajkovich directs all international and domestic sales and marketing strategies, overseeing the brand's development and execution of sales strategies, key account management, and management of the global sales team. Rajkovich holds an MBA from The Fisher College of Business at The Ohio State University.

Research Projects: The Importance of 'Cold Eyes' Project Reviews

Follow this guidance to carry out independent project reviews of research projects that are both valuable and effective — and pain free

Richard Palluzi
Richard P Palluzi LLC

Independent project reviews (IPRs) are a common tool used to control, review and validate a project before making an irrevocable commitment to start the next phase. Common issues often reviewed during an IPR include necessary scope, cost and schedule validity, design readiness, unresolved issues, overlooked problems, validity of assumptions, and confirmation of economic analysis, among others. Often called "cold eyes reviews" (as they are intended to bring a fresh set of "cold" eyes to review the project) — or, less commonly, "murder boards" (due to their tendency to be used to identify areas to cut costs or even kill projects) — IPRs are an excellent tool if used properly.

While already commonly used in large-scale projects throughout the chemical process industries (CPI), IPRs are becoming increasingly common for research projects, as well. This is still a relatively new area, however. As discussed here, the use of an IPR for research projects raises some additional issues. These areas of concern — while often common with larger projects — are somewhat specialized and often slightly (but critically different) when it comes to research projects.

Guidelines for a research IPR

Research projects are very different from process projects for a variety of reasons. The scale of the work is much smaller. The technical challenges are often much greater. Information is usually more limited. Project teams are typically much smaller. Goals and objectives are often less well defined. As a result, simply assuming that an IPR can be conducted the same way for a research project is unrealistic and may doom the effort to a poor outcome. Tips and proven strategies are provided here to help tailor the IPR effort to a research project, with the goal of improving both the process and the outcome.

FIGURE 1. Defining which aspects of the research project should be reviewed, while recognizing those that are either 'a given' or are beyond the scope of the effort, can help make the most of the effort

The IPR sponsors must take the time to define the desired scope of the review in adequate detail in advance. While it may appear a safe path to simply open up any portion of the project to the review, the sponsors need to understand that this requires significantly more time, effort, experience and probably more personnel on the team. In many cases, some aspects of the research project are not realistic for the team to review, as the rationale or justifications are outside the scope of their expertise.

The sponsors should clearly identify decisions that are outside the scope of the review — fo instance, that the new facility is to be taken as "a given" — so that the IPR can focus on more germane issues. For example, the decision to open a new facility in a different region to meet some strategic goals is probably beyond the scope of a normal IPR, and should not necessarily be evaluated during the review.

The IPR sponsors should check in with the team periodically to make sure they are on track, but give the IPR team room and time to work. It is easy for a team to begin down a path that the sponsors did not originally envision (and may not feel is worthwhile). It may also be necessary for the sponsors to occasionally corral a reluctant member (or team) who is having difficulty remaining within the IPR scope. That said, the IPR sponsors also need to give the team room and time to do their work.

It is not uncommon for the sponsors to want frequent updates, in order to get a sense of the preliminary findings. While this can allow the sponsors to make sure the IPR is not drifting off track or encountering problems that may need sponsor help to overcome, it can also lead to "knee-jerk reactions" to issues that often turn out to have been adequately addressed or at least not as serious as first envisioned once further study and analysis have been completed. Strong, experienced and independent team leadership is essential on the IPR team. Such

leaders should hold off on reporting issues prematurely or too frequently, arguing, correctly, that it is too early in the study for anything of real value to be reported.

Pick the best lead possible for the IPR, and make sure they focus on the quality of the result, not just the presentation. The IPR team lead is a visible and desirable position. If done well, it usually can provide a good career boost; however, if done poorly it can be career-deadening. There is a natural tendency for team leaders to work on the final presentation (formal and informal) perhaps more than the content, with adverse effects on the IPR quality.

In my experience, I have found the best team leaders tend to be those who are nearer the end of their careers — individuals who have both the broader experience and a lower fear of consequences compared to those earlier in their careers. Similarly, recent retirees and outside contractors are good candidates, as they are better able to focus on the content of the project review over their perceived performance.

Structure the IPR based on the amount of work that needs to be reviewed, but keep it as small as possible. The IPR team composition is not amenable to a ready formula. My experience suggests that at least three members are needed; rarely is a team with more than five members effective. With fewer members, you typically get a one-person view; any more and excessive time and effort is often expended trying to reach real agreement.

Make sure the IPR has research experience that is both broad and relevant. The IPR team's experience is critical to its success, so members need to be chosen for their experience with research-type projects. There is an unfortunate tendency for sponsors to feel that an experienced project manager is suitable to review any project. Unfortunately, an IPR has limited time and ability to look at the entire continuum of a proposed project. Hence, the members need to have a clear appreciation of what areas they need to look at in detail, versus what areas can quickly be determined to appear satisfactory. There is a natural tendency for the sponsors to want a very "cold eye" — that is, someone from completely outside the field. This is particularly true if the project appears to have potential problems, such as a higher-than-anticipated budget, a longer than desirable schedule, or technical or implementation issues that were not originally envisioned.

FIGURE 2. All projects have different critical steps and a good 'cold eyes' review will help the team to focus on the most critical ones

However, my experience is that this level of "cold eyes" (selecting members based on them having little or no research experience) is usually self-defeating. The outsider, however competent and dedicated, does not have the frame of reference needed to quickly evaluate the issues. Too much time is spent with them trying to understand the differences between their scope of reference and a research program.

This results in less effective — and even occasionally wrong — recommendations. Often the outside member is viewed as having adequate research experience based on casual factors, such as participation in one or two other IPRs on research projects, or time spent in research either far in the past or of very limited duration. When assembling the IPR team, nothing can match the effectiveness of individuals with long-term, focused experience with research programs.

IPR members have to be able to look past their preferred way of doing a project and evaluate whether the project's proposed approach is adequate. IPR members need to be able to look at another project team's work and try to determine if the project team is missing anything of significance. It is often the case that the project team may be planning to do something differently than what the IPR member would have done, or that may have been less than efficient in some areas (especially on issues that become obvious in hindsight). A good IPR member must have the ability to put aside his or her personal preferences, opinions and prejudices, and only raise issues that they feel the project team's planned approach does not adequately address. Too often, IPR reports read like a summary of the members preferred approaches — rather than an objective evaluation of the project team's proposed plan.

Recognize the difference between an IPR for a major process project and a research project. Large-scale CPI projects have significant controls and procedures due to their sheer size and complexity. By comparison, research projects often have much more flexibility and are able to use greatly reduced levels of controls and planning. This lack of very defined procedures for every part of the research project can be a problem for those IPR members without research experience. They often become fixated on what they see as a plan lacking the process structure and controls they would see on a larger project. This leads them to focus on these missing structures as major issues rather than asking

FIGURE 3. The 'cold eyes' review team needs to focus on all of the aspects of the environment in which the project is proposed, to identify any potentially overlooked area of concern

if the project-team plan addresses the research project adequately, albeit with less formal procedures and structures due to its lower complexity or scale.

IPRs require adequate time for the members to review all the information in a fast and efficient manner. To do this effectively, the project team needs to have adequate information available in an organized format. While this should be inherent in all project work, too often long-term team members are so familiar with the key practices and procedures that certain important items are not adequately documented.

Similarly, some approaches have developed over time, either overall within the organization or specific to the project, that are not documented at all, as they have become inherent to any research project. Failure to document these key elements — even those that are recognized organizationally and are already clearly followed methods — is a problem; these elements must be documented so that an outsider can understand fully what is going to happen and, more importantly, can assess the underlying logic that led to these practices. The absence of such information at the beginning not only wastes time for the IPR team, but can leave a lingering sense that the project team has not diligently thought through its approach. This will, unfortunately, increase the project team's work and may delay the onset of the IPR team's work.

The IPR should not be started until adequate information is available in an organized format. Rushing to get the IPR started always takes longer in the end, and almost always produces a product with poorer quality. Everyone involved in the project needs to be realistic about when adequate information is available. There is always a tendency to start with preliminary documents or a verbal review. Sometimes this is successful with a very experienced project team and IPR; but all too often it leads to more questions down blind ends.

IPR members need to avoid any tendency to delve too deeply into the minutiae of the project. This may be due to their personal style (members who are technical specialists versus generalists), a vague unease over a different or non-standard approach, or an excessive desire to be thorough. The IPR team lead needs to understand how to identify this problem and address it promptly.

Project team members should feel empowered to raise any concerns they have to the IPR and not try to keep them "in the family." Project team members should recognize how valuable an IPR can be to their success. The review process gives the project team members an opportunity to raise concerns that they feel have not been addressed. It also allows them to often shape management's occasionally irrational expectations. A frank discussion about the pressure to produce an overly optimistic schedule can often translate into a comment that extra time needs to be allotted for project completion. Demonstrating concern about an unresolved area can lead to sponsor pressure to address a hitherto intractable problem in a timely fashion.

IPR reports need to be crisp and clear, focusing on major issues, and not creating pages of documentation on minor ones. IPR reports should clearly and unequivocally identify those areas the team thinks are going to create significant problems and avoid the all-too-human tendency to list every single item found. IPRs are intended to highlight significant problems that an experienced team thinks could adversely affect the success of a project. What is significant, of course, is open to a wide interpretation. Clearly some items that may have been overlooked or poorly thought through may jump out.

However, there is often a tendency for IPRs to raise every issue they can think of, in order to make sure none is overlooked. This must be strongly resisted. The IPR team has to work hard to separate out the significant issues from those that are routine. Potential issues related to, say, weather, productivity, estimate quality, schedule uncertainty and a host of other issues are always present to some degree or other.

The trick is to identify any issues or concerns that have the potential to significantly affect the project, have not yet been adequately addressed, and are within the project team's control. If, for example, the project team has included no allotment for weather for an outside job in North Dakota in winter, potential schedule-related issues that could arise should be raised. If, however, the team has allocated a week for bad weather in Texas in the fall, raising the concern that a hurricane could delay the schedule further probably isn't necessary.

There is no easy or formulaic approach to this identification. My experience suggests that for an issue to be significant it probably needs to meet most of the following criteria:

- It alone has the potential to adversely affect the cost or schedule by more than 10%

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FIGURE 4. 'Cold eyes' reviews can assist in making larger pilot plant and research projects proceed more smoothly, allowing issues to be addressed and rectified earlier

- It was completely or significantly overlooked by the project team
- The project team's analysis of the effect is deemed by the IPR to be incorrect or at least badly flawed
- The IPR's combined actual experience with the proposed approach has shown significant problems on similar past projects that have not been adequately ameliorated by the project team's existing plan

These are fairly high hurdles, but they provide useful benchmarks to consider, to clearly separate significant issues from potential problems or simple concerns about alternate approaches. Most IPRs should not be finding many significant issues unless the project team is really not qualified or competent.

List less-critical observations in backup information or an appendix, providing clear documentation that these issues have been reviewed with the project team, are being addressed and pose no significant problems. Many, observations in my experience, require no real action and just perhaps a heightened sense of caution or wariness to make sure they do not escalate. Bringing them to the sponsor's attention rarely is necessary. However, when all are raised in the body of the final report they often hide the main issues, create a backlash with the project team (who may feel "nitpicked") and create a sense of unease in some sponsors, particularly those with less experience or more exacting standards, that the project team is not doing its job well enough.

Problems must be clearly and unequivocally stated in the final report. Trying to work the issue so as not to assign blame or needlessly provoke project personnel is certainly desirable — but not at the cost of losing the criticality of the issue. Deciding what is "politically appropriate wording" versus clear communication is never easy. My suggestion is to make sure to state the issue as clearly as possible without any rationale or softening.

IPRs that do not identify any major issues should say so and not fill the final report with minor issues. There is a strong tendency to dig even deeper, to raise any concern that can be seen and to produce something to justify the time and effort. Shouldn't the IPR always seek to suggest better approaches, or identify areas of weakness or concern (no matter how minor), to help make the project better? I don't think mentioning a host of minor issues (if that is all the IPR team could find) to the project team has any downside. However, I do think that raising them to the sponsor level provides little upside.

The project team must have the ability to give its view of the IPR's concerns, to allow them to correct a misconception, clarify an issue or highlight an error. If the process has worked well, the project team will normally tend to agree with the concern and then present proposed corrective measures. The team may sometimes disagree with the IPRs assessment for valid reasons. Usually such a counter argument results from the project team's failure to effectively explain a portion of the plans or rationale related to a given topic, or the occasional unwillingness of an IPR team to accept an alternate approach. Reconciling divergent views is not always easy. The sponsors will have to decide which view to follow or ask for further work. In the latter case, I would suggest that a different person or team address the specific issue in question. Sending the entire IPR and project teams back to work out the issue is often not productive.

Closing thoughts

IPRs for research projects are valuable and useful tools. But like any tool, they can be used less effectively if their limitations are not recognized, and if some basic guidelines are not followed. IPRs are intended to provide a review of the project team's plan. That review is only focused on one specific moment in time. Regardless of how good the IPR is, how carefully its recommendations are followed, or how diligent the review, even the best IPR cannot guarantee a successful project. If the approaches decided upon (by the project team, or recommended by the IPR) are not effective, if the project team does not have the skill and expertise to execute the project, if outside events arise that were not considered, projects will still suffer. However, a good IPR can improve the project's odds of success. ■

Edited by Suzanne Shelley

Author

Richard P. Palluzi, P.E., CSP, of Richard P Palluzi LLC (72 Summit Dr., Basking Ridge, NJ 07920; Email: rpalluzi@verizon.net; Phone: 908-285-3782) is a consultant to the pilot plant and laboratory research community on safety, design and research project management. He retired as a Distinguished Engineering Associate after almost 40 years at ExxonMobil Research and Engineering, where he was involved in the design, construction, and support of pilot plants and laboratories for ExxonMobil's research site in Clinton, N.J., as well as affiliates worldwide. Palluzi is the author of two books, and numerous articles and presentations. He is a past chair of the AIChE Pilot Plant Committee, ExxonMobil's Pilot Plant and Laboratory Safety Standards Committee, and ExxonMobil's Safe Operation Team for their Clinton Facility. He is on the National Fire Protection Association (NFPA) NFPA-45 Fire Protection for Laboratories Using Chemicals and NFPA-55 Industrial and Medical Gases committees. Palluzi also teaches several courses for the University of Wisconsin's Dept. of Engineering Professional Development. He has B.E. and M.E. degrees in chemical engineering from Stevens Institute of Technology.

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Rudy Teng
Sales Representative
Chemical Engineering;
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Economic Indicators

2014 2015 2016

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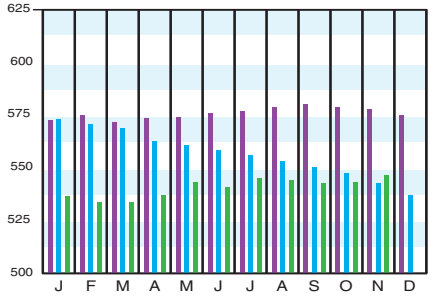
CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957-59 = 100)	Nov. '16 Prelim.	Oct. '16 Final	Nov. '15 Final
CE Index	546.6	543.1	542.8
Equipment	654.0	647.6	648.9
Heat exchangers & tanks	567.6	557.1	566.5
Process machinery	662.7	653.3	653.0
Pipe, valves & fittings	818.9	811.0	803.4
Process instruments	394.2	390.0	386.4
Pumps & compressors	966.0	966.0	956.5
Electrical equipment	510.7	511.5	508.4
Structural supports & misc	707.9	710.4	713.4
Construction labor	326.0	329.3	323.7
Buildings	545.9	546.7	538.9
Engineering & supervision	314.0	313.7	317.1

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

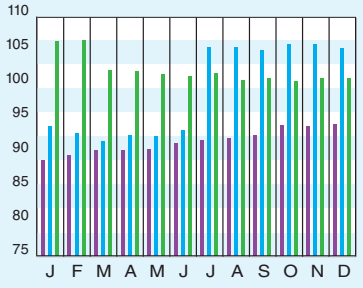
Annual Index:
2008 = 575.4
2009 = 521.9
2010 = 550.8
2011 = 585.7
2012 = 584.6
2013 = 567.3
2014 = 576.1
2015 = 556.8



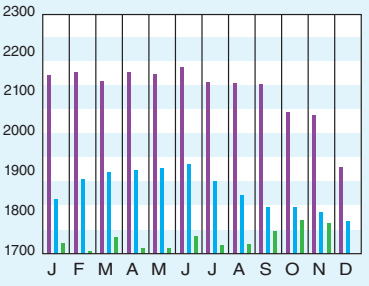
CURRENT BUSINESS INDICATORS

	LATEST	PREVIOUS		YEAR AGO
CPI output index (2012 = 100)	Dec. '16 = 100.9	Nov. '16 = 101.3	Oct. '16 = 100.7	Dec. '15 = 101.5
CPI value of output, $ billions	Nov. '16 = 1,777.2	Oct. '16 = 1,780.7	Sept. '16 = 1,757.8	Nov. '15 = 1,746.6
CPI operating rate, %	Dec. '16 = 74.1	Nov. '16 = 74.4	Oct. '16 = 73.9	Dec. '15 = 74.6
Producer prices, industrial chemicals (1982 = 100)	Dec. '16 = 239.2	Nov. '16 = 239.8	Oct. '16 = 233.4	Dec. '15 = 230.1
Industrial Production in Manufacturing (2012=100)*	Dec. '16 = 103.2	Nov. '16 = 103.0	Oct. '16 = 103.2	Dec. '15 = 103.0
Hourly earnings index, chemical & allied products (1992 = 100)	Dec. '16 = 170.1	Nov. '16 = 169.2	Oct. '16 = 170.8	Dec. '15 = 159.5
Productivity index, chemicals & allied products (1992 = 100)	Dec. '16 = 100.3	Nov. '16 = 100.8	Oct. '16 = 99.8	Dec. '15 = 102.0

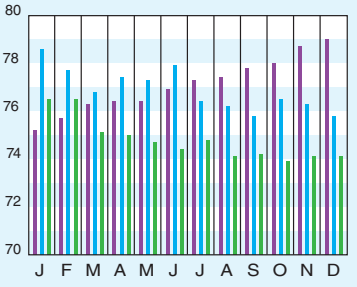
CPI OUTPUT INDEX (2000 = 100)†



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 *CE* Plant Cost Index (CEPCI; top; the most recent available) experienced a jump from the previous month's value, due largely to fresh data on carbon-steel plates from the Bureau of Labor Statistics that pushed the Equipment subindex higher. The Construction Labor and Buildings subindices saw small declines, while the Engineering & Supervision subindex rose slightly. The preliminary November 2016 CEPCI value stands at 0.7% higher than the corresponding value from November 2015. This marks the first time the current value has exceeded the year-before value since January 2015. Meanwhile, the latest Current Business Indicators (CBI; middle) for December 2016 saw a small decrease in the CPI Output Index.

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