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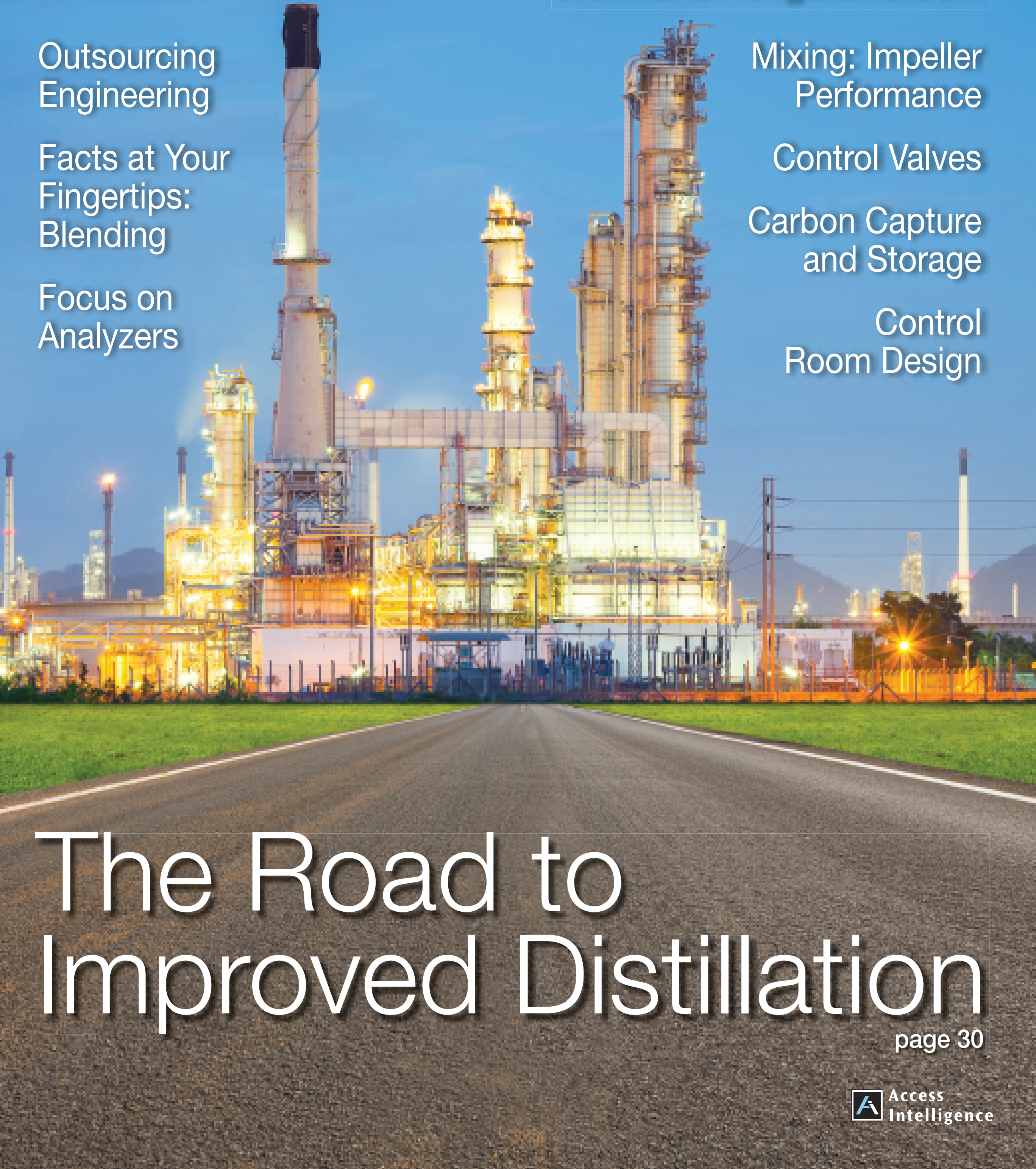

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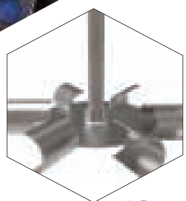

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Editor's Page

Awarding 'green' innovations

The U.S. Environmental Protection Agency (EPA; Washington, D.C.; www.epa.gov) has recently announced the winners of this year's Presidential Green Chemistry Challenge Awards. This recognition is given for innovations that create business opportunities from solutions to potential environmental problems — endeavors that are well worth recognizing and taking note of. The 2017 winners, in each of five categories, are listed here (Source: EPA).

Designing Greener Chemicals — The Dow Chemical Company (Midland, Mich.; www.dow.com) and Paperfabrik August Koehler SE (Oberkirch, Germany; www.koehlerpaper.com) were recognized for creating a thermal printing paper that uses a physical change, rather than a chemical one to create an image, thereby eliminating the need for compounds such as bisphenol A and bisphenol S. The new, patented thermal paper technology incorporates an opaque layer with a polymer that collapses air voids in the paper coating during printing. These voids allow an underlying dark-colored layer to be seen. The paper has been tested in practice and a large-scale commercial introduction is expected this year.

Greener Reaction Conditions — Amgen Inc. (Cambridge, Mass.; www.amgen.com) and Bachem (Bubendorf, Switzerland; www.bachem.com) were honored for process improvements in the manufacture of a peptide drug, Etelcalcetide, used for secondary hyperparathyroidism in adults with kidney disease. While the volume of manufacture for peptide drugs is often small, the expected demand for this drug is high, and so the inefficiencies in the manufacturing process were problematic. The two companies redesigned the process, resulting in a five-fold increase in capacity and a 56% decrease in manufacturing time, while reducing the amount of solvent needed by 71% and completely eliminating an ion-exchange operation.

Greener Synthetic Pathways — Merck & Co., Inc. (Rahway, N.J.; www.msdresponsibility.com) received this award for process improvements in the manufacture of an antiviral drug candidate, Letermovir. Improvements to the process were made by implementing a novel catalyst that decreases raw material costs by 93%, increases the yield by over 60%, and reduces the amount of waste generated. It is estimated that the refined process will decrease the carbon footprint by 89% and water usage by 90%.

Academic Award — This honor went to professor Eric J. Schelter of the University of Pennsylvania (scheltergroup.chem.upenn.edu) for his work on recycling rare-earth-element mixtures. These materials are frequently used, as mixtures, in consumer applications. Schelter's group has developed a simpler, "greener" technology to separate rare-earth elements from consumer products, based on their solubility characteristics and using tailored organic compounds. A grant from the U.S. Dept. of Energy is supporting further work to develop the technology.

Small Business Award —This award was given for an advanced vanadium redox flow battery that was commercialized by UniEnergy Technologies LLC (Mukilteo, Wash.; www.uetechnologies.com). The technology originated from work by Pacific Northwest National Laboratory (PNNL). This third-generation vanadium redox flow battery, the UniSystem, offers a higher energy density and much broader operating temperature than prior chemistries. The new vanadium electrolytes (chloride-based) exhibit improved stability over sulfate-based systems. ■

Dorothy Lozowski, Editorial Director


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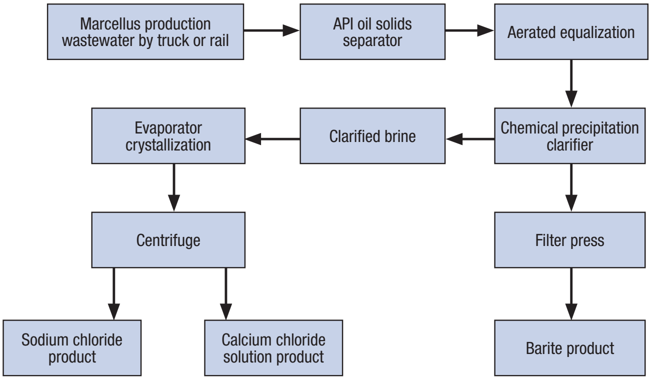
New process generates salable products from Marcellus produced water

Edited by:
Gerald Ondrey



Produced water from natural gas wells in the Marcellus Shale Deposit is extremely high in total dissolved solids (TDS; levels of 25–35% TDS are common) and barium, making the water difficult to re-use and requiring injection in underground geologic formations. A new process is capable of generating salable chemicals from Marcellus produced water (water from hydraulic fracturing wells) and has recently received a U.S. patent. The process will be used in a scaled-up treatment facility that is in the planning stages.

Process developer ProChemTech (Brockway, Pa.; www.prochemtech.com) is currently negotiating possible sites for the first plant using the water treatment technology, which generates barium sulfate (barite), solid sodium chloride and calcium chloride brine from Marcellus produced water.

After an initial physical separation process to remove free oil and suspended solids, the produced water enters aeration tanks where it is chemically equalized to minimize variation of the water properties entering the process. The water enters an inclined plate clarifier, where it undergoes a chemical precipitation process under acidic (pH = 3.5–4.0) and oxidizing conditions to remove barium as barium sulfate.

"The barite obtained from our process is similar in purity to material that is currently available commercially," says Tim Keister, chief chemist with ProChemTech. The $BaSO_4$ is used in drilling mud for the oil-and-gas industry, as well as in glass production and other applications.

Next, the barium-free clarified brine enters an evaporator-crystallizer unit that removes solid sodium chloride for the water softener market. Finally, the remaining calcium chloride liquor is diluted to about 30% solution using water from the process for use as a de-icer, Keister explains.

ProChemTech plans to build a plant capable of processing 200,000–250,000 gal/d produced water that will be trucked in from Marcellus wells. "The sale of the chemicals covers the operating costs of the plant, and we will charge tipping fees for the water to make a profit," Keister says. The company estimates ten such sites would be needed to handle all Marcellus production water currently generated.

DESALINATION

Recently, Formosa Petrochemical Corp. (FPCC; Mailiao, Taiwan; www.fpcc.com.tw) commissioned IDE Technologies (Kadima, Israel; www.ide-tech.com) to build a desalination plant in Yunlin County, Taiwan that will be the first large-scale application for IDE's high-purity boron-removal process. The three-step process combines reverse-osmosis (RO) membrane technologies (seawater RO followed by four stages of brackish-water RO) with an ion-exchange system that employs a specialized resin to absorb boron, says Dotan Gur, turnkey projects director at IDE Technologies.

IDE's desalination technology is said to be the world's first to reach the stringent boron concentration level of 0.01 parts-per-million (ppm) at the scale required by FPCC for its co-generation process plant. "With water of this purity, FPCC will be able to circulate the water required for cogeneration up to 100 cycles," explains Gur. This purity will also help to meet local regulations for blowdown water discharge. This technology has been installed at much smaller water-treatment plants, but never at such a large scale — the FPCC plant will have a capacity of 105,000 m^3/d and

(Continues on p. 8)

A new catalyst for making methane from CO_2 and H_2

The Sabatier reaction, in which H_2 and CO_2 react at temperatures of 300–400°C in the presence of a nickel catalyst, or an alumina-supported ruthenium catalyst, is one way to reduce CO_2 into methane. Until now, however, it has been difficult to find efficient, resilient catalysts with good selectivity. A promising candidate has been developed by the research group of professor Christian Doonan at the University of Adelaide (Australia; www.adelaide.edu.au) and colleagues from CSIRO (www.csiro.au). The catalyst — a ruthenium-impregnated zirconium-based metal-organic framework (MOF) — could pave the way for producing carbon-neutral fuels.

The new catalyst is based on a commercially available zirconium terephthalate MOF called UiO-66. The group used a wet impregnation method to introduce $RuCl_3$ into the pores of the activated MOF. The catalyst was dried and activated for testing in a fixed-bed microreactor. A mixture of H_2 and CO_2 (with a 4-to-1 mole ratio) was flowed over the top of the catalyst. The best results were obtained at temperatures of 330–350°C and a pressure of 500 kPa. Under these conditions, the catalyst converted 96% of CO_2 into methane, with 99% selectivity. The only observed byproduct was CO. Also, the catalyst remained stable and active and retained its selectivity to methane, even after more than 160 h of testing.

Doonan says the group's research priorities are now a technical and economic assessment and development of scale-up methods. "We are also trying to fully determine the structure of the Ru species."

is slated to begin commercial operation in about two years.

SOLAR PAINT

A paint that makes H_2 in the presence of water and sunlight is being developed by researchers at RMIT University (Melbourne, Australia; www.rmit.edu.au), led by Torben Daeneke. The so-called solar paint combines two components: a new catalytic material developed by the researchers — synthetic molybdenum sulfide, which also acts as a silica gel to absorb water; and titanium dioxide, which absorbs ultraviolet (UV) light and transfers the energy to the catalyst, where it is used to split the absorbed water. Simply adding the new material can convert a brick wall into a fuel producer, with several liters of H_2 produced on a few square meters. "There is no need for clean or filtered water. Any place with water vapor in the air — even remote areas far from water — can produce fuel," Daeneke says.

The researchers are now focusing on increasing the system's efficiency, and on developing an economical way to collect the H_2. Daeneke says the solar paint would require the incorporation of additional layers to the system, such as membranes. Such membranes already exist, and could be applied as a simple additional coating on top of the paint, he says.

HEAT TRANSFER FLUID

Wacker Chemie AG (Munich; Germany; www.wacker.com) and Royal Tech CSP Ltd. (Changzhou, China) have signed an agreement to intensify cooperation for highly efficient solar-thermal systems that are based on concentrated solar power (CSP) technologies. Under the terms of the agreement, Wacker will supply its newly developed Helisol silicone fluid to Royal Tech, its exclusive partner in China. Royal Tech uses the silicone fluid as a heat-transfer medium in its solar power plants. Helisol can withstand thermal stress of up to 425°C

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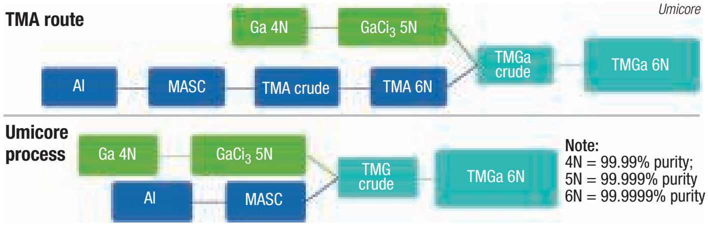
A 'greener,' more sustainable route to trimethylgallium



Last month, the Precious Metals Chemistry business unit of Umicore AG & Co. KG (Hanau-Wolfgang, Germany; www.pmc.umicore.com) inaugurated its production unit for making trimethylgallium (TMGa) and triethylgallium (TEGa). The new facility uses a new, patented production process to make these metal-organic precursors. Compared to conventional methods, Umicore's process requires two less synthesis steps, minimizes hazardous side streams and achieves nearly quanitative yields (based on Ga).

TMGa is a colorless liquid with very high vapor pressure that boils at low temperatures. It is used in the semiconductor industry, where it evaporates in closed systems to deposit onto a substrate Ga-containing semiconductor layer (for example, GaN used in light-emitting diodes).

Up to now, the two main routes for making TMGa are alkylation of $GaCl_3$ with either a Grignard reagent, or with trimethylaluminum (TMA), explains Oliver Briel, director of Global Business Electronics. The Grignard route suffers from large volumes of organic solvents needed, and the fact that oxygen is present in the reaction mixture (because of the ether used), which makes it difficult to reach O_2 levels below 1 ppm. As a result, yields are limited, while generating an MgX_2-laden waste stream, explains Briel. The drawback of the TMA route (upper diagram) is that only one methyl group per TMA can be transferred to Ga, thus generating a wastestream with $AlCl(Me)_2$.

In contrast, Umicore's process (lower diagram) does not use an organic solvent, but instead performs the alkylation in a molten salt (a $KCl/NaCl/AlCl_3$ mixture with melting point of less than 130°C), explains Briel. Also, a more efficient methylating agent is used — methylaluminumsesquichloride (MASC). This reduces the amount of waste per kilogram of TMGa by more than 50%, with the resulting intermediates being recycled in the process, he says. "In the end, we have a pure salt (with only a few ppm of Ga) as side stream, and can convert nearly 100% of the Ga to TMGa (or TEGa)," he says.

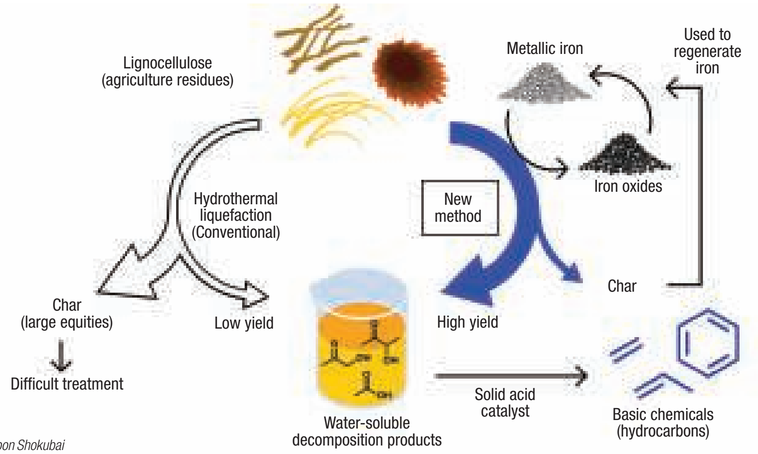
Bio-based xylitol lowers production costs

While demand for the artificial sweetener xylitol grows, expensive raw materials and low yields have kept production prices high. Now, a new process from S2G BioChem (Vancouver, B.C., Canada; www.s2gbiochem.com) aims to produce xylitol in a more cost-effective way, utilizing byproducts from pulp-and-paper plants and biorefineries as feedstock. "These are growing sources of xylose-rich sugars that we can take advantage of," says Mark Kirby, president and chief executive officer of S2G Biochem. He explains that while these feedstocks are not typically suitable for traditional xylitol manufacturing processes, the high efficiency of S2G's method makes their use feasible. According to Kirby, S2G's technology can achieve xylitol yields double that of traditional processes. Another factor contributing to the economics of the process is the production of saleable co-products, including ethylene glycol and propylene glycol. "Whatever we don't turn into xylitol, we turn into high-value biochemicals," explains Kirby.

In S2G's process, fractionated biomass is cleaned and conditioned and then sent to a trickle-bed catalytic hydrotreating process employing a non-rare-earth catalyst in a packed bed. In the presence of hydrogen, the sugar content is converted into sugar alcohols, including xylitol. The remaining sugars are further processed and converted into bioglycols. Finally, crystallization is used to isolate the xylitol, and a distillation step separates the bioglycols. The benefits of a catalytic biomass transformation versus a biological process, such as fermentation, include a faster conversion time, scalability and the ability to run continuously.

S2G has operated a xylitol pilot plant since 2012 and intends to construct a larger-scale demonstration biorefinery in Sarnia, Ont. that will produce over 2,000 metric tons per year (m.t./yr) of xylitol. Full-scale operation is expected to commence in 2019. For the construction of the new biorefinery, S2G has seen support from several industry partners, including global food company Mondelez International.

Make more from biomass with iron



Nippon Shokubai

Nippon Shokubai Co. (Osaka and Tokyo, Japan; www.shokubai.co.jp) has jointly developed a new process for biomass utilization in collaboration with professor Yuichi Kita at Kobe University (www.kobe-u.ac.jp). The process is highly efficient for decomposing lignocellulose into a group of water-soluble compounds that consist mainly of 2–6 carbon atoms. It is carried out in hot water at 250–300°C in the presence of metallic iron. Unlike the conventional methods, this method reduces useless consumption of biomass resources and enables an efficient utilization of the whole biomass. Furthermore, by using a solid acid catalyst, such as ZSM-5 zeolite, the obtained water-soluble compounds can be converted to olefinic hydrocarbons, such as ethylene, propylene and butylene, or aromatic hydrocarbons, such as benzene, toluene and xylenes.

With such sustainable building blocks, Nippon Shokubai estimates it could reduce the production cost of raw materials for superabsorbent polymer (SAP) down to 30%. In collaboration with chemicals manufacturers, the company aims to use this technology industrially after 2020.

In conventional hydrothermal liquefaction (diagram, left), high-temperature water thermally decomposes biomass into water- and oil-soluble decomposition products. However, in the absence of metallic iron, the product yields are low (around 15 wt.% for both fractions). Moreover, the oxygen content in the decomposition products is high, so additional deoxygenation steps are necessary. One of the biggest challenges facing this process is the large quantity (around 40 wt.%) of char produced.

In the new process (diagram, right), metallic iron, which coexists and reacts in a reactor, increases the yield of water-soluble decomposition products to about 60 wt.%. The oxygen content of these products is reduced to about 20% that in the raw material. Moreover, decomposition, deoxygenation and hydrogenation can be further promoted by adding a metal that has a hydrogenation capability, such as copper or palladium. Finally, the whole biomass can be efficiently utilized, because the byproduct char can be used as a reducing agent for regenerating metallic iron.

A probe that tests galvanizing kettles at high temperatures

To provide corrosion protection and long life, steel products are galvanized by immersion into kettles containing molten zinc. These galvanizing kettles need to be checked periodically to monitor rates of corrosion in order to avoid a catastrophic spillage of molten Zn. Previous monitoring techniques either used an external probe, or else the galvanizers had to drain the zinc from the kettles, which were then cooled sufficiently to enable physical sampling of the kettle surface. Such methods are time consuming and costly.

Now, a quicker, direct method for inspecting kettles has been developed at Sonemat Ltd. (Albridge, Walsall, U.K.; www.sonemat.com) from research at the University of Warwick (U.K.; www2.warwick.ac.uk), and is being commercialized by Zinco UK Ltd. (Hereford; www.zincouk.com) in its new Zinc Immersion Probe (ZIP) technology, which can perform safety critical testing while submerged in molten Zn.

All the internal components of the ultrasonic transducer inside the sensor are designed to survive temperatures of 450°C without any cooling, explains professor Steve Dixon, director of the Center for Industrial Ultrasonics at the University of Warwick (www.ciu.ac.uk).

Ultrasound travels from the sensor head into the liquid Zn, which is then coupled into the steel wall of the kettle. Two reflected signals are then detected by the sensor: one from the zinc/kettle-wall interface, and the other from the outer wall of the kettle. Simple analysis of the signals provides the time it takes the ultrasonic wave to travel through the kettle wall, and hence the thickness of the remaining steel kettle wall can be calculated, says Dixon.

The new technology is very portable and is quick and easy to use, and can be done in routine short gaps in production, leading to the significant cost savings, Dixon says. “The cost saving of using this technology compared to a more traditional technique of pumping the zinc out and then inspecting the kettle after cooling is approximately £20,000 [$26,000] per inspection if we consider cost of pumping and testing (excludes the resulting production downtime),” he says. “What is even more interesting is that the data that the system provides can enable more regular and affordable testing that can boost production efficiency, improve safety and extend kettle life.”

There are currently two units being operated by Zinco with more being built to order.

for a long period of time and its viscosity remains low even at –40°C. In combination with Royal Tech's parabolic trough collectors, the fluid enables efficiency levels that are not possible with conventional heat-transfer fluids (see *Chem. Eng.*, February 2017, pp. 15–18). Currently, Royal Tech is building a 50-MW solar power plant in the city of Yumen in western China.

OSN MEMBRANES

Evonik Industries AG (Essen, Germany; www.evonik.com) and the Sinopec Beijing Research Institute of the Chemical Industry (BRICI; China; www.sinopec.com) have signed a collaboration agreement to build a process development laboratory for organic solvent nanofiltration (OSN) membrane technology. OSN is an innovative and environmentally friendly membrane technology that has a wide range of applications in the petrochemical, pharmaceutical, fine chemicals and food industries.

When Evonik initiated the first contact with BRICI in 2015, both parties showed strong interest in potential OSN applications for the petrochemical industry. In 2016, a series of laboratory-scale tests were successfully conducted for a lube-oil-dewaxing application. The joint OSN laboratory was officially established earlier this year. In the future, the laboratory will focus on the petrochemical industry to open up markets in both China and the entire Asian region for OSN applications.

LT WGS CATALYST

Scientists from Brookhaven National Laboratory (Upton, N.Y.; www.bnl.gov) have developed a new low-temperature (LT) catalyst for performing the water gas shift (WGS) reaction for producing high-purity H_2 while simultaneously removing CO. The discovery — described in a recent issue of *Science* — has potential implications for H_2-based fuel cells, which are prone to CO poisoning. The catalyst — a cluster of gold nanoparticles layered on a molybdenum-carbide substrate — was synthesized and tested by collaborators at Peking University (China). ❑

Vehicle fuel tank for adsorbed natural gas moves toward commercialization

Natural gas vehicles (NGVs) are attractive because of the low cost and wide availability of natural gas, plus the ability to connect to residential and business gas lines for fueling. Among the challenges for using natural gas as a fuel for light-duty vehicles is engineering a fuel tank that can contain a sufficient amount of natural gas safely and in a space-efficient volume that is still cost-effective for cars. As a vehicle fuel, compressed natural gas (CNG) — at pressures of 3,000–3,600 psig — requires large thick-walled cylindrical tanks that have a limited ability to conform to available spaces in cars or light trucks. In addition, the cost of compression equipment is prohibitive for light-duty vehicle use.

A manufacturing coalition is now commercializing a natural gas fuel tank that uses activated carbon to adsorb the fuel. Adsorbed natural gas (ANG) enables increased natural gas storage at much lower pressures (<1,000 psig) and, as a result, tank designs that are much more flexible in how they can be shaped to fit into vehicle bodies. Also, the lower pressure allows more reasonably priced compression equipment for home and business vehicle fueling directly from low-pressure natural gas pipelines.

One of the companies involved in the tank commercialization is specialty chemical maker Ingevity (North Charleston, S.C.; www.ingevity.com), the developer of shape-specific activated carbon monoliths for ANG fuel tanks that allow sufficient volumetric fuel capacity for vehicles, while still maintaining the sustainable adsorption and desorption properties needed for ANG-powered vehicles.

Ingevity's proprietary process for making activated carbon from sawdust generates a pore-size distribution that is tuned precisely for mixed hydrocarbon fuel use in vehicles (gasoline vapor, natural gas). For making the monolith, the company uses a proprietary binder material with its activated carbon to achieve a carbon density high enough to be viable in vehicle-fuel applications.

"Ingevity utilized its considerable expertise in activated carbon for fuel-vapor-emissions control-systems activated carbon to tune the pore size distribution to allow 'catch and release' — that is, high levels of adsorption, but also a robust desorption of fuel in a controlled depressurization process," explains BP Holbrook, senior product research scientist at Ingevity.

Ingevity's activated carbon monoliths will be used within a proprietary tank design exclusively licensed by coalition partner Adsorbed Natural Gas Products Inc. (ANGP; Chester, N.J.; www.angpinc.com).

"We are currently manufacturing conformable ANG tanks for certification testing, and are in discussions with automakers about using them in bi-fuel 'hybrid' vehicles capable of running on natural gas and gasoline," Holbrook says.

A new zeolite catalyst promises to significantly improve naphtha cracking

Chiyoda Corp. (Yokohama, www.chiyoda-corp.com) has been working on a new naphtha catalytic-cracking process with the aim of producing more propylene and consuming less energy than existing naphtha thermal-cracking methods.

The company has recently developed a new catalyst based on iron- and gallium-modified MFI-type zeolite (0.5–0.6-nm dia. pore), and successfully used it for the catalytic cracking of naphtha. Iron- and gallium-modification suppresses the polymerization of aromatics, which induce coking that shortens the catalyst life. The company has completed a small-scale demonstration project, which has been supported by the New Energy and Industrial Technology Development Org. (NEDO) since 2015. The technology could be ready for commercial applications in 2021.

The new catalyst was shown to enhance the yield of propylene to 30%, compared to 15% typically obtained in conventional cracking furnaces. The company believes the new catalyst has a longer lifetime, having demonstrated continuous operation of more than 1,000 h in an inexpensive fixed-bed reactor. Other features of the new process include: a 10–15% reduction of naphtha usage; a 60% reduction in energy consumption (by operating at a lower temperature of 565°C); and a reduction in steam consumption by 50% (by eliminating the need for steam injection that is required for operation at 850°C). The company also believes the process can be flexible for producing ethylene-rich or BTX-rich (benzene, toluene, xylenes) production through optimizing the composition of iron and gallium in the catalyst and the cracking conditions. ■

1000-Gallon

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Plant Watch

Arkema invests in capacity expansion for biosourced polyamide 11

July 12, 2017 — Arkema (Colombes, France; www.arkema.com) plans to invest around €300 million over five years in the biosourced polyamide 11 chain, building a new production plant in Asia that will boost its polyamide 11 production capacity by 50%. The new plant, which will produce both the amino 11 monomer and its polymer, Rilsan PA11, should come onstream in late 2021.

Braskem selects Linde for EPC work on new polypropylene plant

July 11, 2017 — Braskem (São Paulo, Brazil; www.braskem.com.br) selected the Linde Group (Munich, Germany; www.the-linde-group.com) as the lead engineering, procurement and construction (EPC) contractor to build Braskem's polypropylene (PP) production line. Braskem has committed up to $675 million towards the design and construction of the new PP plant, which will be located in La Porte, Tex. and have a production capacity of 450,000 metric tons per year (m.t./yr) of PP.

Sadara starts up propylene glycol plant

July 10, 2017 — Sadara Chemical Co. (Jubail, Saudi Arabia; www.sadara.com), a joint venture (JV) developed by The Dow Chemical Co. (Midland, Mich.; www.dow.com) and Saudi Aramco (Dhahran; www.saudiaramco.com), announced that it has successfully started up its propylene glycol (PG) plant. The new PG plant marks the 22nd of Sadara's 26 plants at Jubail to start up.

Total starts up ethane-based petrochemical production in Antwerp

July 7, 2017 — Total S.A.'s (Paris, France; www.total.com) petroleum-refining and chemicals platform in Antwerp has started up production of ethylene using ethane feedstock extracted from natural gas. Total has invested nearly $60 million to revamp one of the platform's two steam crackers and to adapt the site's terminal to enable the import of 200,000 m.t./yr of ethane.

Chandra Asri selects CB&I for furnace revamp project

July 5, 2017 — PT Chandra Asri Petrochemical Tbk (CAP; Jakarta, Indonesia; www.chandra-asri.com) has awarded a material supply agreement to CB&I (The Woodlands, Tex.; www.cbi.com) for the revamp of existing furnace facilities at CAP's naphtha cracker plant. The furnace revamp is expected to be completed in the first quarter of 2020. Construction will commence in the third quarter of 2018. The revamp will increase CAP's production capacity as follows: ethylene capacity will increase by 40,000 m.t./yr; propylene and pyrolysis gas (py-gas) by 20,000 m.t./yr each; and mixed C4 by 15,000 m.t./yr.

Ingevity to build activated-carbon extrusion plant in China

June 28, 2017 — Ingevity Corp. (North Charleston, S.C.; www.ingevity.com) will build a new activated-carbon extrusion plant in Changshu, China, to meet growing demand for pelletized carbon products primarily for use in vapor-emission control systems. It is expected to be operational by the fall of 2018. The plant represents an investment of approximately $20 million, and will be able to accommodate an additional extrusion line.

Shin-Etsu Chemical to double production capacity of rare-earth magnets

June 28, 2017 — Shin-Etsu Chemical Co. (Tokyo, Japan; www.shinetsu.co.jp) will double the production capacity of rare-earth magnets in Vietnam's Hai Phong Province. As a result of this expansion, the production capacity will increase from 1,100 m.t./yr to 2,200 m.t./yr. The completion of the construction project is scheduled for the middle of 2018.

Chevron Phillips reaches mechanical completion of new Gulf Coast PE units

June 19, 2017 — Chevron Phillips Chemical Co. (The Woodlands, Tex.; www.cpchem.com) announced that the two polyethylene (PE) units of its $6-billion petrochemical investment on the U.S. Gulf Coast successfully achieved the milestone of mechanical completion. Once operational, each PE unit will produce at least 500,000 m.t./yr.

PPG completes €45-million manufacturing plant in Russia

June 16, 2017 — PPG Industries, Inc. (Pittsburgh, Pa.; www.ppg.com) marked the opening of a €45-million ($49-million) paint and coatings manufacturing facility in the Lipetsk region of Russia. The site will produce approximately 25 million L/yr of coatings at full capacity.

Mergers & Acquisitions

Eastman sells Dynaloy business to Versum Materials

July 13, 2017 — Versum Materials, Inc. (Tempe, Ariz.; www.versummaterials.com) has agreed to acquire Dynaloy, LLC from Eastman Chemical Co. (Kingsport, Tenn.; www.eastman.com) for approximately $13 million. Dynaloy is a supplier of formulated cleaning solutions for the semiconductor manufacturing industries. The transaction is expected to close during the fiscal fourth quarter of 2017.

Perstorp acquires Polialcoli business from Polioli

July 10, 2017 — Perstorp Holding AB (Malmö, Sweden; www.perstorp.com) has announced the acquisition of Polialcoli S.r.l. from Polioli S.p.A. The agreement includes production capabilities for neopentyglycol (Neo), trimethylolpropane (TMP) and trimethylolpropane diallylether (TMPDE), as well as the associated formate businesses located at the Vercelli site in Italy.

Solvay to sell stake in Brazilian PVC joint venture

July 6, 2017 — Solvay S.A. (Brussels, Belgium; www.solvay.com) has agreed to sell its 50% stake in Brazilian polyvinyl chloride (PVC) compound processor Dacarto Benvic to its three JV partners in Brazil. The closing of this transaction is expected by year-end 2017.

AkzoNobel announces a pair of coatings acquisitions

July 3, 2017 — AkzoNobel (Amsterdam, the Netherlands; www.akzonobel.com) has announced the acquisition of U.K.-based Flexcrete Technologies Ltd. and French manufacturer Disatech. Flexcrete manufactures products primarily used for the protection and repair of concrete substrates. Disatech specializes in the manufacture of self-adhesive vinyl, polyester and polycarbonate films.

Amec Foster Wheeler completes sale of CFB boiler business

June 28, 2017 — Amec Foster Wheeler (London, U.K.; www.amecfw.com) announced that it has completed the sale of its circulating fluidized-bed (CFB) boiler business to Sumitomo Heavy Industries, Ltd. (Tokyo; www.shi.co.jp), for a consideration of $170 million. In addition to the sale of the CFB boiler business, Amec Foster Wheeler has already completed the sale of a number of smaller assets.

Umicore to acquire Haldor Topsøe's diesel and stationary catalyst businesses

June 20, 2017 — Umicore N.V. (Brussels, Belgium; www.umicore.com) has reached an agreement to acquire the heavy-duty diesel and stationary catalyst businesses of Haldor Topsøe A/S (Lyngby, Denmark; www.topsoe.com) for an enterprise value of approximately €120 million. The businesses serve customers from production plants in Denmark, China, Brazil and Texas, as well as R&D facilities in Lyngby.

Air Products and Linde join forces for East Coast Nitrogen venture

June 16, 2017 — Air Products (Lehigh Valley, Pa.; www.airproducts.com) has formed a new JV with Linde North America named East Coast Nitrogen (ECN) and will build a new world-scale air separation unit (ASU) and industrial gas liquefier in Glenmont, N.Y. An approximate capital investment of $60 million will be made in the new facility, which will produce liquid nitrogen, liquid oxygen and liquid argon. The new plant will be constructed and operated by Air Products with commercial status targeted for December 2018. ■

Mary Page Bailey

New CO_2-Capture Approaches Push Against Cost Hurdles

Despite cost hurdles, CO_2-capture technologies continue to advance, driven by the critical role of CO_2 capture in achieving emissions-reduction goals

IN BRIEF

Among the possible strategies for addressing climate change risks are CO_2-removal approaches, including the capture of CO_2 from large emitters, such as power plants and industrial facilities, and also the capture of CO_2 from ambient air. These technologies have been explored for some time, and commercialized in some cases, but have yet to be deployed widely, largely because of cost issues.

Driven by the importance of carbon capture and sequestration (CCS) within the overall climate change response, the field of carbon capture for storage and re-use is advancing at a rapid pace. Efforts are afoot to lower the costs associated with capturing CO_2 using amine-based solvents, as well as to develop alternative CO_2-capture methods and ways to utilize captured CO_2.

This article discusses some of the recent technological advances for CO_2 capture methods for both re-use and sequestration.

CCS and climate response

The Paris Climate Accord, signed in April 2016, set a goal of keeping the global average temperature rise due to greenhouse gas emissions to 2°C or less above pre-industrial levels by 2100. To explore the economic ramifications of reaching that goal, the International Energy Agency (IEA; Paris; www.iea.org), the Intergovernmental Panel on Climate Change (IPCC; Geneva, Switzerland; www.ipcc.ch) and others have constructed cost models that include various possible climate change response scenarios. These models suggest that the costs of achieving the goals of a 2°C rise and lower than 450 ppm atmospheric concentration of CO_2 would be considerably higher without the widespread deployment of CCS. For example, IPCC models put the figure at 138% higher without CCS.

A recent report by the Global Carbon Capture and Storage Institute (Docklands, Australia; www.globalccsinstitute.com) states "It is not possible to envisage least-cost emissions reduction scenarios, consistent with the Paris Agreement, that do not include broad deployment of CCS."

Putting a price on carbon

While CCS figures to play a key role in climate change response, many believe that ultimately, the widespread deployment of CCS will only occur by establishing a price on carbon, through taxes, a cap-and-trade market or other means. "The main hurdles to wider CCS deployment are policy and incentives," says Luke Warren, CEO of the Carbon Capture and Storage Association (CCSA; London; www.ccsassociation.org). "The key is a price on carbon and a reward for low-carbon products, whether that be heating, electricity or industrial products." Carbon capture projects thus far have been carried out on a "case-by-case" basis, with unique local factors playing a large role in making the projects economically feasible.

Geoff Holmes, director of business development at Carbon Engineering Ltd. (Squamish, B.C.; www.carbonengineering.com) says "In the absence of a carbon cap-and-trade system or tax or other means of placing a price on carbon emissions, there is no financial incentive to permanently sequester the carbon."

While the absence of carbon taxes and other means to price carbon has slowed the widespread use of CCS, it has also spurred investment in ways to re-use the CO_2 after it is captured.

Evan Price, CEO of CO_2 Solutions (Quebec, Canada; www.co2solutions.com) predicts that CO_2 sequestration will probably be used going forward, but CO_2 will increasingly be recycled and utilized for other purposes. A major current trend in this area is an influx of investment into so-called second-generation uses for CO_2, Price says. "These include uses that go beyond using the CO_2 for enhanced oil recovery (EOR) and carbonation, and more toward conversion of CO_2 into biofuels, or incorporation of the CO_2 into plastics and other materials, such as concrete."

Driving CO_2-capture costs down

Regardless of whether the CO_2 is sequestered or recycled, the capture technology will be critical, and its current costs are hindering its wider deployment. For example, fossil-fuel-powered electric plants outfitted with conventional amine-based post-combustion CO_2-capture systems use 15–25% of their steam for regenerating CO_2 from the capture solvent [see sidebar, p. 16], so electricity production is reduced, explains Stan Lam, process engineering manager at Koch Modular Process Systems (Paramus, N.J.; www.modularprocess.com).

"There are many technical challenges to CO_2 capture, but lowering energy usage is the most important," Lam says. "You're always fighting to reduce the parasitic power losses that are imposed by conventional CO_2-capture systems. And, as is true for most things, there's no 'free lunch' — to reduce parasitic power loss, you must spend more money on additional equipment," he says.

Despite the challenges, a number of forces are at play that may help to drive costs for CCS down, including research and development by academia, governments and private companies, as well as standardization, optimization and economies of scale. In May, a group of experts began developing a research agenda for CCS (see sidebar, p. 17). "The tradeoffs for CCS projects are difficult, but there is continuous improvement going on along a number of fronts," Lam remarks. "There is a great deal of research work on carbon capture technologies and it's not yet clear how much advancement can or will be made. It's like the four-minute-mile barrier in track sports — eventually someone will make a breakthrough and it will then become a common practice," he says.

As Oscar Graff, head of carbon capture and storage at Aker Solutions (Lysaker, Norway; www.akersolutions.com), points out, "Since [the Paris Accord], we have seen a significant rise in interest in carbon capture technology across a range of different industries that emit CO_2, such as oil and gas, fossil-fueled power, aluminum, ammonia, cement, steel and waste-to-energy. While carbon capture and storage costs are currently high, the costs are likely to come down as more plants are put in operation, allowing the technology to benefit from economies of scale and standardization," he says.

Improving amine-based capture

Several ongoing efforts are aimed at lowering costs for amine-based CO_2 capture. For example, Aker Solutions has developed a proprietary cocktail of water and amine solvents to absorb CO_2 from fluegases post-combustion. "Our process uses 35% less energy compared with a standard amine reference plant," says Graff. Also, the Aker Solutions amine solution is non-toxic, biodegradeable and non-corrosive, which reduces the stainless steel required in the capture plant, thereby reducing costs, Graff explains.

The company has demonstrated and tested its technology in a mobile pilot plant, which has allowed

Carbon Engineering

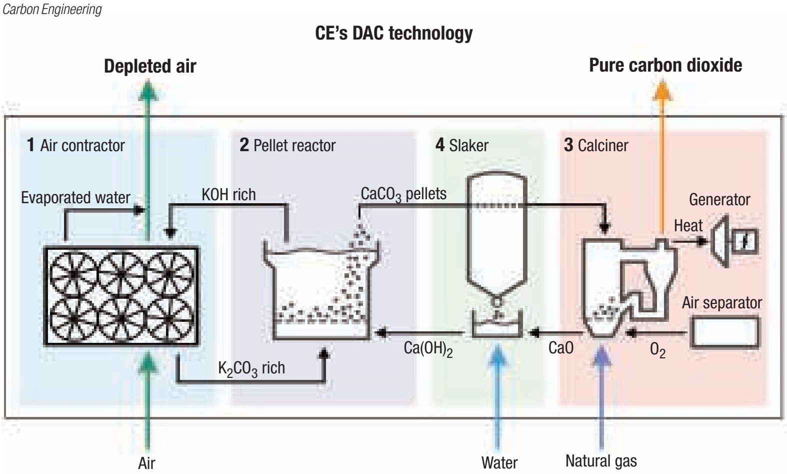


FIGURE 2. Carbon Engineering has developed a system for direct air capture of CO_2 that combines several existing technologies from different industry sectors

Aker Solutions to capture CO_2 from both coal and natural gas combustion. Aker Solutions technology has been selected for use in two facilities seeking funding from the Norwegian government — one involves a CO_2-capture facility for a cement plant, and the other is at an ammonia plant. In addition to developing the proprietary solvent, Aker Solutions has also developed an anti-mist system, which minimizes the emissions reaching the outside air, Graff says.

Koch Modular's Lam says his company's expertise in column design and modular construction can also have an impact on amine-based CO_2-capture costs. Modular construction can lower costs by 15–20% by reducing labor requirements and compressing schedules, Lam says.

Koch Modular designed and supplied a complete modular carbon capture system, including all column internals, for a research and testing facility operated by the University of Kentucky (Lexington; www.uky.edu), where scientists are working to reduce costs and improve performance of amine-based CO_2-capture solvents. A unique challenge was that the system needed to be designed for generic MEA-based solvent, while allowing researchers to test various additives aimed at lowering energy requirements, increasing CO_2 absorption levels and others, says Lam.

Solid sorbents

Also pursuing CO_2-capture cost savings is Global Thermostat LLC (GT; New York, N.Y.; www.globalthermostat.com), which is developing technology for using solid amine sorbents, (rather than liquid solvents) to absorb CO_2. The technology works by blowing air (or an air-fluegas mixture) over a wall of honeycomb contactors (Figure 1). These monoliths allow contact with large volumes of air at small pressure drops and low cost. The honeycomb monoliths are coated with a proprietary solid amine-based sorbent material. Recent advances in the sorbent materials, the honeycomb monoliths and the design of the system have increased the efficiency of GT's technology so that it is capable of producing CO_2 at \$50 per ton or less, if low-temperature residual heat is available, says company co-founder Graciela Chichilnisky. Along with the solid sorbent and honeycomb contactors, GT has patented a rotating system for improving the efficiency of the two main processes — capture and desorption.

After research and testing in two pilot plants, GT is currently completing work on two commercial-scale facilities in Alabama. Chichilnisky says the technology can be used to purify CO_2 to food-grade levels.

Non-amine solvents

CO_2 Solutions (Quebec, Canada; www.co2solutions.com) takes a different approach to carbon capture from industrial emitters by employing the enzyme carbonic anhydrase (CA) to allow the use of low-grade heat and to avoid toxic chemicals. Ubiquitous in nature, CA quickly converts CO_2 to bicarbonate in respiration. The company has developed a method of directed evolution in a host microbe to adapt the natural version of CA for industrial conditions. By using the enzyme to convert CO_2 to bicarbonate quickly, they can avoid the use of amine-based solvents for adsorption and desorption. "Ordinarily, potassium carbonate solution would be too slow to be effective in carbon capture applications, but with the addition of the enzyme, the reaction occurs quickly and KCO_3 can be used as a solvent," says Evan Price, CEO of CO_2 Solutions. "We are able to strip the CO_2 at a much lower temperature than with tradi-

AMINE-BASED CO_2 CAPTURE

The most common method of capturing CO_2 from fluegas has involved the use of amine-based solvents, such as monoethanolamine (MEA), diethylamine (DEA), methyl diethanoloamine (MDEA), piperazine (PIPA) and 2-amino-2-methylpropanol (AMP). Such chemical solvents have desirable properties, in that they often react strongly and quickly with CO_2, yet they also release the CO_2 while regenerating the solvent. Amine-based solvents are able to remove large amounts of CO_2 from fluegas at low pressures. Fluegas from utility and industrial boilers typically contains mostly nitrogen (about 70 vol.%), smaller amounts of water and CO_2 (about 20%), and impurities of SO_2, NOx, mercury and ash particulate matter. An air-pollution control system must be in place to greatly reduce the presence of these impurities in the fluegas before entering the carbon capture system. The cleaned fluegas then enters a small scrubber vessel to cool the gas and remove more trace sulfur impurities. From the quencher, the fluegas enters the absorber. The absorber uses the amine as a solvent to reduce the CO_2 level in the fluegas. This exothermic reaction typically removes about 85–90% of the CO_2 from the entering fluegas. The CO_2-rich solvent mixture is then sent to a heat exchanger before entering the regenerator. In the regenerator, the solvent is steam-stripped, causing the essentially pure CO_2 to come out of solution in an endothermic reaction. The overhead CO_2 is then compressed and fed to a pipeline, while the CO_2-lean amine solvent is recycled back to the absorber for reuse. ❑

tional amine solvents, so we can use low-grade heat and avoid placing a parasitic load on a plant," says Price. The result is 99.95%-pure CO_2 with no contaminants (the extra volume is molecules from air).

"The high cost and toxicity of amines are big issues that remain unresolved to this day," Price says, "and this makes the use of our environmentally friendly enzymatic solvent especially attractive."

After a successful demonstration of the technology at a scale of 10 ton/d of CO_2, CO_2 Solutions has signed its first commercial agreement with a pulp mill, in which CO_2 is captured and piped to a nearby greenhouse, where the gas will aid crop growth. The installation will collect 30 ton/d of CO_2. No compression of the CO_2 is required, keeping costs low

Direct air capture

The possibility of CO_2-reuse scenarios has spurred interest in direct air capture (DAC) systems for scrubbing CO_2 directly from ambient air. DAC systems are not in direct competition with traditional CCS technology, Carbon Engineering's Geoff Holmes says, DAC offers a different set of opportunities.

"We are looking at how to utilize the CO_2 to generate low-carbon fuels," Holmes explains, "so our premise has been to scrub CO_2 directly from the air at commercial scale."

Carbon Engineering's technology has industrial precedents and is based on well-understood operations. "For example, the design and operating concepts of our air contactor for scrubbing CO_2 from the air is borrowed from cooling tower technology. We use a high-surface-area structured packing, through which a strong potassium hydroxide solution flows down," Holmes says. CO_2 is scrubbed from air in a continuous regeneration-loop process (Figure 2). As CO_2 from the air contacts the thin film of hydroxide solution in the column, potassium carbonate forms. The potassium carbonate enters a pellet reactor, into which calcium hydroxide is added to form a precipitate of $CaCO_3$, and regenerate the KOH. The $CaCO_3$ is calcined to yield CO_2 and CaO, which is then reacted with water to regenerate $Ca(OH)_2$ for the process. The pure CO_2 resulting from the process can be re-used, sequestered or, in the case of Carbon Engineering, be used for fuels synthesis in a second stage. Also, the heat required for calcination is provided by oxy-fired natural gas consumption, Holmes says, so all combustion CO_2 produced in powering the air-capture plant is delivered along with that which is captured from the air.

The company has constructed a pilot plant for the DAC system and the regeneration loop at its British Columbia headquarters, and is now adding a second stage to the pilot for the fuel synthesis. "Our intellectual property is really in the knitting together of the entire process and designing the process to work efficiently," Holmes says. All of the chemistry for the DAC process is already well known.

Carbon Engineering plans to couple the DAC with a second phase designed to thermo-catalytically react CO_2 to generate synthesis gas and use Fischer-Tropsch synthesis techniques to generate diesel and jet fuel. Hydrogen will be supplied by electrolysis of water using renewable power, the company says.

Another DAC company reached a milestone in 2017. On May 31, 2017, Climeworks (Zurich, Switzerland; www.climeworks.com) announced the startup of the world's first commercial-scale direct-air capture (DAC) plant, capable of collecting 900 ton/yr CO_2. It collects the CO_2 from ambient air and pipes the pure CO_2 gas to a nearby greenhouse, where it is pumped into the greenhouse to increase crop yields.

The Climeworks technology is based on a cyclic adsorption and desorption process that depends on a new filter material that specifically adsorbs CO_2. During adsorption, atmospheric carbon is bound to the sorbent's surface. Later, it is driven off the sorbent by heating it to 100° C to yield high-purity CO_2. The sorbent can be reused for many cycles. Low-temperature heat covers 90% of the energy demand, making the process relatively cheap, the company says. ■

Scott Jenkins

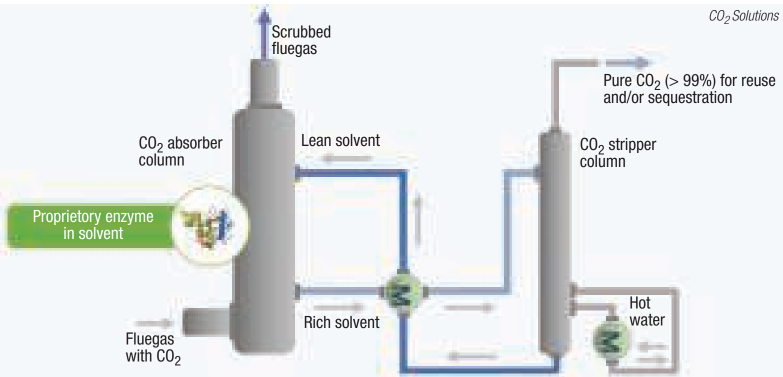


FIGURE 3. CO_2 Solutions employs the enzyme carbonic anhydrase as part of the capture process

RESEARCH AGENDA FOR CO_2 CAPTURE AND REMOVAL

Under the auspices of the U.S. National Academies of Science, Engineering and Medicine (NAS; Washington, D.C.; www.nationalacademies.org), an expert committee has been assembled to develop a research agenda for CO_2 removal and reliable sequestration. Chaired by Princeton University scientist Stephen Pacala, the committee recently held the first of six planned meetings to identify the "most urgent unanswered scientific and technical questions" related to the potential of various carbon dioxide removal technologies and their commercial viability, according to the committee's statement of task. In addition to direct air capture and the coupling of bioenergy with CCS, the committee will also be looking at geologic sequestration, land management and other technology areas. NAS says the committee anticipates publishing a report in summer 2018. In addition to the group developing this research agenda, there is a separate NAS committee forming specifically to look at CO_2 re-use. ❑

For additional information on CO_2 recycling, commercial-scale CCS operations and more, view the online version of this article at www.chemengonline.com.

Bringing Increased Reliability and Safety to Control Valves

Hardware improvements and service programs add more value to today's control valves

IN BRIEF

ADVANCED HARDWARE

REDUCED FUGITIVE EMISSIONS

INCREASED USE OF DIGITALIZATION

AFTER-MARKET SERVICES

Chemical processors demand reliability, safety and efficiency when selecting control valves. As a result, there have been significant advances to the equipment, including the use of better materials of construction, improved packing technologies and added intelligence. In addition, suppliers have begun offering service programs that further promote reliability and efficiency.

"When it comes to control valves, not only is there value in offering improved equipment that can reliably and safely handle the demanding processes, high temperatures and high pressures of the chemical industry, but also there is value in developing the ability to get everything running smoothly around that," explains Ismo Niemela, director, Neles Control Valve Product Center, with Metso Flow Control (Helsinki, Finland; www.metso.com). "There is more to it than providing quality valves that can function in the process industries. We want to help our customers become more efficient, more reliable and safer in their operations and that requires more than hardware or a physical product. That requires service programs and partnerships designed around these goals."

Advanced hardware

Although the control valve market is fairly well established, that hasn't stopped valve manufacturers from working to increase the reliability and safety of their products through various improvements, such as developing advanced components, designing valves to withstand harsh conditions and using better seal technologies to control fugitive emissions.

The best way to improve valve performance is to improve the components and the way to do that is to study and understand the flow phenomena that takes place inside the control valve and to develop new trim parts and overall control valve packages that are able to withstand and better handle what's taking place inside the valve, says David Tamm, senior manager, product management and R&D, with Samson Controls (Baytown, Texas; www.samsoncontrols.com). "This is even more important as the chemical industry continues to progress in process technologies that employ higher pressures and temperatures and new chemicals, so manufacturers need to continue to evolve and find new materials and manufacturing methods in an effort to develop valves that can withstand the challenges of these applications," he says.

Samson Controls

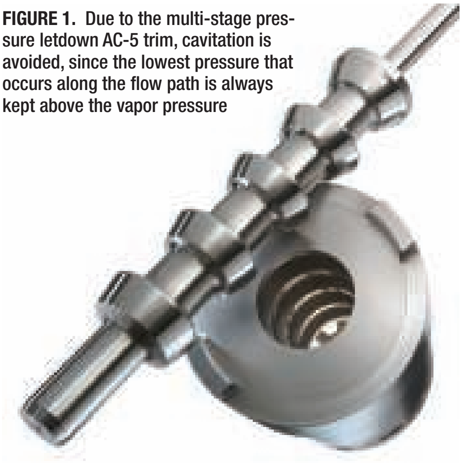


FIGURE 1. Due to the multi-stage pressure letdown AC-5 trim, cavitation is avoided, since the lowest pressure that occurs along the flow path is always kept above the vapor pressure

Specifically, Samson has been working on improving trim components for the seat and plug of the control valve because those are the most critical components for maintaining good control and where the highest velocities from flow occur, making these components the most susceptible to damage. "We continuously look at improved designs and new manufacturing technologies so we may develop new internal components that previously weren't possible or were not economically feasible," he says. One of the latest offerings is the multi-stage pressure letdown AC-5 trim developed by Samson Controls, which helps prevent cavitation, since the lowest pressure that occurs along the flow path is always kept above the vapor pressure. This allows pressure drops of up to 200 bars to be handled without any problems (Figure 1).

By studying flow and improving inter-

SOR Controls Group

FIGURE 2. The 1451 Freezeless control valve was developed for fluid control in oil-and-gas separators and other process vessels so that the plug and seat are able to be constantly submerged in the process media due to the valve body design, allowing the natural heat of the process to prevent freezing during actuation of the valve

nals, Samson has also been able to develop several control valves for critical and challenging applications. For example, the 3291 heavy-duty, seat-retained globe control valve is designed for general service applications up to the limits of the ANSI 900 pressure class rating. Service applications include difficult process conditions with erosion, abrasion, corrosion, cavitation and flashing. And, the Vetec 82.7 double-eccentric, rotary-plug control valve for both standard and critical service applications, including process events such as erosion, abrasion, corrosion, cavitation and flashing, is able to increase flow capacities with only a minor reduction in the pressure recovery factor, making the design a suitable replacement for linear globe control designs, even when cavitation and flashing conditions are present.

Also in an effort to meet demanding applications, SOR Controls Group (Lenexa, Kan.; www.sorinc.com) aims to provide custom materials for its valve internals that meet the requirements of chemical compatibility and harsh conditions, such as those with both debris and high velocities in the valve line, which would ordinarily cause erosion and destroy the trim. "We have the ability to make the internals of special, custom materials, such as tungsten carbide, that won't abrade or erode under such conditions," says Matt Gasparovich, product manager with SOR. "While the ability to accommodate the special needs of our customers via custom process connections, special seal materials and custom trim materials is essential to meeting their needs for chemical compatibility and harsh conditions, we're also finding that processors need these highly customized valves quickly. If they have a valve that stops working, they need a replacement ASAP [as soon as possible] so we're working on providing engineered-to-order control valves with off-the-shelf speed to increase reliability and efficiency."

In addition to customized materials, SOR has also developed a "freezeless" valve for challenging applications in extremely low temperatures where ordinary control valves freeze and hang up. The 1451 Freezeless control valve was developed for fluid control in oil-and-gas separators and other process vessels so that the plug and seat are able to be constantly submerged in the process media due to the valve body design, allowing the natural heat of the process to prevent freezing during actuation of the valve (Figure 2).

Reduced fugitive emissions

For applications where safety — namely eliminating fugitive emissions — is a concern, valve manufacturers are working on better seal materials and techniques for control valves. "External leakage and fugitive emissions are very challenging with control valves, especially linear control valves," notes Samson's Tamm. "Because when you tighten packing down, it clamps down on the valve stem, which generates friction and can deteriorate control, so we want the seal to be tight enough to prevent fugitive emissions, but not so tight on the plug stem that it deteriorates control and causes the process to be inefficient."

Bürkert Fluid Control Systems

FIGURE 3. Burkert's Models 8690 through 8694 offer from little to no communication all the way up to continuous process control with full PID control and many bus options. A contact-free, analog position sensor measures the position of the valve and commissioning is simplified through automatic tune functions. Shown here is Model 8693

Because of the importance of reducing emissions, Samson offers it's environmentally friendly packing as its standard packing, versus adding it as an up-charge, says Tamm. And for applications that require even tighter seals, the company can provide its environmentally friendly, hysteresis-free bellows seal, which guarantees zero leakage over the entire service life of the control valve.

Blake Coleman, global chemical industry manager/flow controls, with Emerson Automation Solution's Fisher Valves division (St. Louis, Mo.; www.emerson.com) agrees that this is becoming an area of increasing importance. "In the chemical industry there is constant pressure to reduce emissions, so we are improving packing technologies to reduce fugitive emissions and to provide zero emissions valves for lethal or toxic services via a reliable bellows bonnet solution." He says many chemical customers have started standardizing on live-loaded packing, such as the company's EnviroSeal, which applies a constant force to the packing so that, over time, as the packing begins to wear, a constant force is applied to the seal on the valve stem, ensuring a good seal throughout the life of the packing to help reduce emissions. An EnviroSeal bellows seal bonnet is also available for hazardous services.

Increased use of digitalization

While tougher materials and better sealing technologies help with reliability, both reliability and efficiency can be further enhanced via digitalization of valves, which allows the equipment to transmit information about the valve, says William Ban-

Emerson Automation Solutions

FIGURE 4. Emerson's Fisher division offers the FieldVue DVC6200 digital valve controller to help users obtain data that can be used for diagnostics that help increase reliability. It is a HART communicating instrument that converts a 4–20-mA control signal into a pneumatic output to an actuator

ham, engineering technician with Bürkert Fluid Control Systems (Huntersville, N.C.; www.burkert-usa.com). "Reliability may be built into a valve, but it can also be boosted if users can look at information about the valve that will allow them to predict when maintenance is needed rather than performing routine preventive maintenance," he says. "Especially in the process industries, the ability to manage and see, in real-time, what the valves are doing is a huge benefit that allows technicians to be proactive instead of reactive."

But, because each plant is different in how communications are handled — some have decentralized communications and others are centralized — Bürkert provides solutions that accommodate various communications scenarios via its line of digital controllers and positioners for integrated mounting on process control valves. Models 8690 through 8694 offer from little to no communication all the way up to continuous process control with full proportional-integral-derivative (PID) control and many bus options. A contact-free, analog position sensor measures the position of the valve and commissioning is simplified through automatic tune functions. A close-tight function, curve characteristic selection, switching manual/automatic operation features, as well as a software interface tool, can be used for a number of operation customizations (Figure 3).

Similarly, Emerson's Fisher division offers the FieldVue DVC6200 digital valve controller to help users obtain data that can be used for diagnostics that help increase reliability (Figure 4). It is a HART communicating instrument that converts a 4–20-mA control signal into a pneumatic output (I/P) to an actuator. The instrument can be retrofitted in place of existing analog positioners on most Fisher and non-Fisher pneumatic actuators. The two-stage positioner design provides quick response to large step changes and precise control for small set point changes and can detect position feedback problems and automatically revert to I/P transducer mode to keep the valve operational. The self-diagnostic capability of the controllers provides valve performance and health evaluation without shutting down the process or pulling the valve assembly from the line. "The digital communication provides easy access to the condition of the valve, so sound process and asset management decisions can be made by analysis of valve information through Fisher ValveLink software," says Coleman.

Metso recently introduced the Neles NDX valve controller (Figure 5), which helps monitor valve performance and stores data in its memory. The data can be used to plan maintenance and provide an alarm if something has gone wrong with the valve, says Metso's Niemela. "The controller can bring operational savings," he says. "It offers high pneumatic capacity for fast operation with large volume actuators without the need for extra instrumentation, low supply-air consumption and built-in valve diagnostics for efficiency and cost reduction in valve maintenance."

Metso Flow Control

FIGURE 5. Neles NDX valve controller helps monitor valve performance and stores data in its memory. The data can be used to plan maintenance and provide an alarm if something has gone wrong with the valve

This is especially helpful because in the chemical industry valves are often selected for maintenance based upon history, which means too many valves are maintained without actual need and many other valves that may require maintenance often go without, says Niemela. "By having digital diagnostics, users can clearly see which valves need to be maintained and can effectively plan shutdowns, order spare parts and plan for labor."

Often, digital controls can be tied into a monitoring system for enhanced control. "Metso's Expertune PlantTriage has helped many customers improve control and increase process performance. They can read diagnostics from the valve, take measurements and look at various parameters for an in-depth view of how the valve is performing," explains Niemela.

After-market services

With the recent introduction of digitalization, processors often have good digital data available, but don't have the ability to use it to optimize their processes due to a lack of resources. "It is not always easy to find qualified professionals to analyze the data, manage inventory, perform and record maintenance and carry out the other necessary activities for reliable and efficient valve operation," says Niemela.

For this reason, several valve manufacturers are stepping up their game with the introduction of after-market service programs designed to help users in these areas.

Metso, for example, offers Installed Base Management to help users optimize maintenance, operations and spare parts. As part of this service, Metso experts conduct a tag-by-tag inspection to verify field device details. In addition to correctly identifying installed devices, visual condition is also assessed. An installed-base audit gives up-to-date and accurate information to ensure that spare parts are at hand and any issues are promptly identified. With this information, Metso can also recommend relevant maintenance activities to support plant availability, process performance and risk control. "These days it is not easy to find good professionals, so more and more of our customers are relying on us as a partner who can provide those capabilities," says Niemela.

And, embracing cloud-based technologies to take service to the next generation, Coleman says Emerson provides Control Valve Connected Services, which enables remote Emerson experts to continuously monitor critical control valves and generate actionable data to optimize performance. The continuous, non-intrusive health monitoring service delivers predictive analysis. The service analyzes a variety of diagnostic data collected from digital valve controllers to identify potential control valve failures before they cause significant interruptions to a plant's operations. The monitoring program makes use of tools and smart technologies such as Fisher FieldVue digital valve controllers.

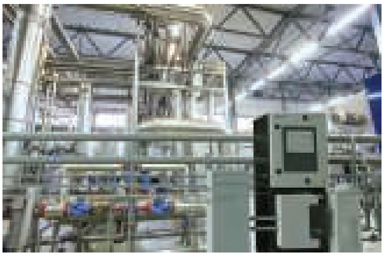
"Our customers use this service on their most critical control valves," says Coleman. "On a routine basis, we would pull diagnostic data and run our analysis tools so we can see the increase of degradation and use the information for trending purposes. Through this time-series analysis, we can see that a valve may soon require maintenance before it becomes a 'red light' situation and we can alert our customers to schedule and prepare to maintain the valve before there's a potential issue." ■

Joy LePree

Analyzers and Monitoring Devices

B&W Tek

Electro-Chemical Devices



PANalytical

Improved Raman spectrometer identifies materials

The i-Raman Pro ST (photo) is a portable, high-throughput Raman spectrometer that uses the company's patent-pending "See Through" technology, which enhances the Raman signature of the content. This added functionality allows for the identification of materials inside visually opaque containers, such as white plastic bottles and paper envelopes. Its relatively large sampling area significantly improves analysis reproducibility for heterogeneous samples, and its minimized power density enables the measurement of darker materials that could be susceptible to photo damage under conventional Raman spectroscopy, says the company. The integrated system has a built-in tablet computer that is pre-installed with the company's intuitive software, allowing for material identification and realtime predictions. — *B&W Tek, Newark, Del.*
www.bwtek.com

Multi-purpose liquid analyzer connects directly to any DCS

The modular S80-T-80 Analyzer System (photo) encompasses several analytical devices that provide liquid analytical measurements via HART communications, ensuring simple direct connection with a distributed control system (DCS). The HART-compatible T80 Universal Transmitter helps to streamline operations by providing one single-channel, loop-powered device designed for the continuous measurement of pH, ORP, pION, dissolved oxyen, turbidity, conductivity or resistivity in a general-purpose industrial setting (thereby eliminating the need for multiple devices). This versatile device is also available with a choice of 4–20-mA output, Modbus RTU, Ethernet (with Modbus TCP), SDI-12 serial communication and Profibus PA output. — *Electro-Chemical Devices, Anaheim, Calif.*
www.ecdi.com

Monitor stream composition during production processes

The Epsilon Xflow system (photo) is an online solution for the continuous analysis of the elemental composition of any liquid. It provides realtime feedback for many different process streams and production processes, including petrochemicals, polymers and food. Predefined conditions can be closely monitored, allowing operators to react quickly to any changes, thereby avoiding waste, off-specification product and unnecessary expenses. The system relies on energy-dispersive X-ray fluorescence (EDXRF) technology, a robust and non-desctructive apporach that ensures low detection limits and highly accurate and reproducible analysis results. — *PANalytical, Almelo, the Netherlands*
www.panalytical.com

Capacitance meter measures water in oil with high accuracy

The density or API gravity of crude petroleum varies due to many factors, including temperature, material changes and region or formation from which it is extracted. Those changes can cause standard monitors to mistakenly attribute changes in density to changes in water content, if not properly accounted for. The Universal IV Density Compensated Water Cut Monitor with Multi-Cal Density Compensation (photo) automatically compensates for density changes that may occur in the composition of products, and reduces the calibration requirements due to those changes. Its updated firmware allows for up to 10 different density calibration points. This reduces recalibration requirements and ensures maximum accuracy from load to load, says the company. The Universal IV CM is said to offer the industry's highest pressure and temperature capabilities (1,500 psi and temperatures up to 450°F), as well as field-proven Cote-Shield

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

technology, which is said to make it impervious to coating buildup on the probe. — *Ametek Drexelbrook, Horsham, Pa.*
www.drexelbrook.com

Measure up to 12 gases for improved process analytics

The Rosemount CT5400 (photo) continuous gas analyzer combines tunable diode laser (TDL) and quantum cascade laser (QCL) technologies within the same analyzer, and uses a patented "laser chirp" to provide near-instant, high-resolution spectroscopy to detect and identify a range of molecules in both the near- and mid-infrared range of spectroscopy. This provides significantly quicker response time (sub-second measurement times), and enables measurement levels from sub-ppm to percent levels, says the company. With its modular and scalable design, the CT5400 can incorporate up to six high-resolution laser modules to detect, measure and monitor up to 12 critical components simultaneously, eliminating the need for multiple analyzers and sample-handling systems. — *Emerson Process, St. Louis, Mo.*
www.emersonprocess.com

Handheld analyzer targets combustion gases, emissions

The E6000 handheld combustion gas and emission analyzer (photo) measures up to six gases simultaneously. It has a built-in printer and full color graphic display, automatic data storage, expanded internal memory, and Bluetooth wireless communication and software. It includes up to six gas sensors — O_2, CO, NO, NO_2, SO_2, C_xH_y (HC) and H_2S. It includes a dilution pump for CO auto-range measurements up to 50,000 ppm. The analyzer can also perform temperature and pressure measurements, and has an internal data memory to hold data of up to 2,000 tests. It is designed for boiler, furance, engine and other combustion applications. — *E-Instruments International, Langhorne, Pa.*
www.E-Inst.com

Emerson Process

E-Instruments International

QED Environmental Systems

Fixed analyzer monitors methane and more

The Landtec Biogas 3000 fixed gas analyzer (photo) provides continuous monitoring of gas-producing applications such as anaerobic digestion, biogas and landfill operations. It can use up to four sample ports to monitor methane, carbon dioxide and oxygen, with optional monitoring of hydrogen sulfide, hydrogen and carbon monoxide levels. The device is easy to install, calibrate and maintain, says the company. Recently added capabilities include a built-in liquid level monitoring feature equipped with a dedicated alarm and moisture-removal drain, and an automatic drain option that empties the catchpot without manual intervention, offering flexibility for on-site maintenance. — *QED Environmental Systems, Ann Arbor, Mich.*
www.qedenv.com

Improved flow modulator supports broader GC use

Insight (photo) is a flow modulator for routine, comprehensive, two-dimensional gas chromatography (GCxGC). Thanks to simplified technology that avoids the use of liquid nitrogen, this device helps to reduce the cost and ownership of GCxGC systems, whose complexity often presents a major barrier to use for some laboratories, says the company. Insight uses precise control of gas flows to simply fill and flush a sample loop to fractionate the first-column effluent and deliver it to the second column. The simplified design is said to fit easily inside standard GC ovens, and uses reverse fill/flush dynamics to provide improved peak shape and increased peak capacity for GCxGC compared to first-generation flow modulators. Insight provides separation of volatiles from C1 to C40 and above without using liquid nitrogen, and eliminates modulation breakthrough for improved characterization of both high-loading and trace components. — *SepSolve Analytical Ltd., Peterborough, U.K.*
www.sepsolve.com ■

Suzanne Shelley

Circle 12 on p. 62 or go to adlinks.chemengonline.com/66431-12

New Products

Direct mass-flow measurement for large-diameter pipes

MT100 Series multipoint thermal mass flowmeters (photo) provide temperature-compensated direct mass-flow measurement of air and gases in large-diameter pipes, stacks and rectangular duct installations, where there are often challenges in achieving successful flowmeter installation and performance. To help overcome issues associated with distorted flow profiles, low flowrates and wide turndown rates, as well as hot, moist or dirty gas conditions, MT100 Series devices are available with two to eight flowrate-sensing points. Multiple sensors are inserted at various depths within a pipe or duct, and their outputs are multiplexed and averaged to produce the flowrate within the process line. The meters can measure flowrates over a wide range with 100:1 turndown, and with accuracy of ±0.75% of reading, ±0.5% of full scale. They are also dual-function and can provide temperature measurement capability from –50 to 850°F, with accuracy of ±2°F. — *Fluid Components International, LLC (FCI), San Marcos, Calif.*
www.fluidcomponents.com

Devote less time to pipe repairs with these new fittings

New MegaPress stainless-steel press fittings (photo) can reduce the time required to make pipe repairs compared to other pipe joining systems, reducing downtime and the potential for losses in revenue. According to the manufacturer, MegaPress fittings enable secure connections in 7 s or less, reducing installation time by up to 60% compared to welding or threading. Designed for Iron Pipe Size (IPS) stainless steel, the fittings are equipped with the patented Smart Connect feature, which allows installers and maintenance personnel to easily identify unpressed connections during pressure testing. — *Viega LLC, Broomfield, Colo.*
www.viega.us

Portable analysis system for hazardous chemical identification

The Griffin G510 gas chromatograph-mass spectrometer (photo), is a portable chemical identifier that enables users to sample solids, liquids and vapors to rapidly identify chemical hazards in the field. The instrument's multiple integrated sample inlets simplify on-scene analysis. When used in survey mode, it identifies vapor-phase chemicals within seconds. Featuring a 9-in. touchscreen, the Griffin G510 can be operated while wearing full personal protective equipment (PPE). When a chemical threat is automatically identified using an industry-standard NIST library, the Griffin G510 alerts the operator with audible, visual and color-coded alarms. Designed to withstand harsh environments, the Griffin G510 is IP65-rated, dust-tight and spray-resistant. — *FLIR Systems, Inc., Wilsonville, Ore.*
www.flir.com

Reducing emissions from low-pressure storage tanks

The Enardo ES-665 spring-loaded thief hatch for use on low-pressure storage tanks (photo) is engineered with increased sealing forces, as well as with a tight and consistent fit of the sealing surfaces, resulting in emissions-reduction performance of 0.10 std. ft^3/h at 90% of setpoint. The ES-665 provides tank access, as well as pressure and vacuum relief, to accommodate tank pressure changes that occur under normal conditions. The ES-665 also limits hatch emissions when pressure or vacuum relief is not required. The device also features an available center assembly for improved performance of previously installed models, multiple relief settings and material options and a latching and lockable lid for added security. — *Emerson Automation Solutions, St. Louis, Mo.*
www.emerson.com

Vacuum conveyors built for explosive applications

The risk of explosion due to dust is a major operational concern in many industry sectors. To address this, the E-Line vacuum conveyor (photo, p. 26) is designed to be fitted with either an explosion-venting or explosion-suppression system, based on application requirements. The National Fire Protection Association (NFPA) has been creating stricter guidelines for manufacturers' processes, and

Fluid Components International

Viega

FLIR Systems

Emerson Automation Solutions

Hapman

source machinery that is explosion diffusing is becoming a necessity for compliance. In order for an explosion-diffusing system to function properly, the conveyor canister must be able to contain a certain level of pressure (up to 14.5 psi) before the system activates. With the ability to add explosion venting or suppression, the E-Line provides an alternative solution to purging material-handling systems with nitrogen, which can be a costly process. — *Hapman, Kalamazoo, Mich.*
www.hapman.com

Atlas Copco

Cut energy costs in half with these vacuum pumps

This company expands its GHS-VSD+ series of variable-speed driven vacuum pumps with the addition of three new models, extending pumping capacities up to 4,800 m^3/h. The new GHS 3800-5400 VSD+ rotary screw pumps (photo) are particularly suited for large industrial vacuum users with high vacuum requirements, such as in the glass industry, in packaging lines, and for drying processes. In particular, they support the conversion of several decentralized pumps to a central vacuum supply. With the GHS VSD+, users can significantly increase their productivity. Compared to conventional rotary-vane vacuum pumps, the GHS VSD+ can achieve energy savings of 50%, says the manufacturer. The amortization period for a converted supply is extremely short, says the company. — *Atlas Copco Kompressoren und Druckluft-technik GmbH, Essen, Germany*
www.atlascopco.de

Fox Thermal Instruments

World's fastest battery-powered NDIR CO_2 sensor

The new, ultra-fast SprintIR6S nondispersive infrared (NDIR) sensor for CO_2 can take up to 20 readings per second, with a six-times faster response rate than the current SprintIR sensor. The ultra-fast response is particularly relevant to monitor that the correct levels of CO_2 are being used. For example, in the food packaging industry, high levels of CO_2 are used to keep food fresher for longer periods of time. On the production line, a sensor is needed to measure that the bags are being sealed with the correct level of CO_2, which can be up to 100% concentration. The sensor must be able to work on small sample volumes and produce a result very quickly. The SprintIR6S needs less than 2 mL of sample gas. The sensor is available in measurement ranges from 0 to 100%. — *Gas Sensing Solutions Ltd., Cumbernauld, Scotland*
www.gassensing.co.uk

Tri-Mer

Advanced sensor technology reduces flowmeter vibrations

The Model FT4A thermal mass flowmeter (photo) is designed for monitoring pure gases, mixed gases and complex flare-gas compositions. Three onboard gas-selection menus encompass numerous configuration options. The meter features non-cantilevered advanced sensor technology that eliminates sensor element vibration, which can potentially cause metal fatigue or failure. Also available with these instruments is the CAL-V in-situ calibration validation routine, which allows users to quickly confirm that the meter is functioning properly. Included software enables easy adjustments to the meter, evaluation of alarm conditions and collection of data. — *Fox Thermal Instruments, Inc., Marina, Calif.*
www.foxthermalinstruments.com

This technology offers increased filtration area

This company's Tri-Flow Compact filter technology (photo) is an alternative to HEPA filters for submicron particulate matter and fumes. Tri-Flow offers filtration efficiencies of 99.9999% for particles larger than 0.5 µm with two to three times more filtration area than traditional filter bags, says the manufacturer. Tri-Flow filters are self-supporting; media is pleated and continuously bonded for maximum stability. Aerodynamic gasketing optimizes pulse-cleaning efficiency and self-cleaning filter elements are easy to maintain with integral pulse-jet cleaning. — *Tri-Mer Corp., Owosso, Mich.*
www.tri-mer.com

Hybrid wiped-film and fractionation systems

This company's Hybrid Still technology (photo, p. 27) is designed to separate extremely heat-sensitive fine chemicals and other substances. These systems combine the gentle evaporating principle of dynamically mixed and

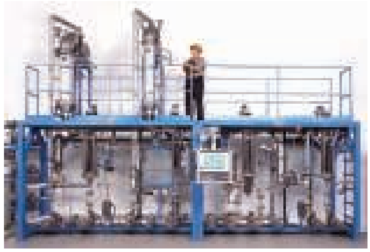
transported wiped thin films with the highly efficient multiple-plate separation capability of fractional columns. Benefits of the technology include short residence time, high vacuum and multiple-plate operation, which provide high purity and yield, with low degradation. Typical applications include purification of edible and essential oils, esters, pharmaceuticals, foods, flavors, fragrances, polymers, extracts, vitamins, waxes, silicones, specialty fine chemicals and many others. Hybrid Still systems are available from 0.1-kg/h bench-top units to pilot-plant and full processing scale, with feedrates up to 1,000 kg/h. The versatile design allows configuration for molecular (short-path) distillation, evaporation or fractionation, plus a choice of glass, 316L stainless steel, Hastelloy or other materials. Complete pilot and production turnkey skid-mounted systems are available, and partial systems and components are also offered. — *Pope Scientific Inc., Saukville, Wisc.*
www.popeinc.com

Configure this flow monitor without opening its enclosure

The Blancett B3100 Series flow monitor (photo) is a flexible, digital signal-processing platform for demanding flow-metering applications. Data logging, remote data access and programming are available without opening the instrument's enclosure. The display shows flowrate, total flow, measuring units and a flowrate-indicating speedometer, with hourly flow totals and settings easily logged in an archive. The B3100 flow monitor processes a frequency output from a flowmeter and interprets the signal to calculate flowrate and total flow simultaneously with 16-point linearization of the flow curve (with interpolation) for improved accuracy. The unit features simplified *K*-factor and engineering unit configuration for volumetric or mass readings. The B3100 is explosion-proof, and a 1-in. NPT thread is provided for flowmeter mounting. — *Badger Meter, Inc., Milwaukee, Wisc.*
www.badgermeter.com ■

Mary Page Bailey and Gerald Ondrey

Pope Scientific



Badger Meter

Blending

Department Editor: Scott Jenkins

Blending is a fundamental chemical unit operation, and there are a handful of common ways to implement it. Blending applications can be either manual or automated, and can be carried out either as a batch or continuous process. There are advantages and drawbacks to each blending approach, and the information provided in this one-page reference can offer direction in selecting from among them.

Table 1 outlines the key pros and cons for the different types of blending systems.

TABLE 1. PROS AND CONS OF BLENDING APPROACHES

	Manual batch blending	Automated batch blending	Continuous inline blending
Pros	Highest degree of flexibility	Preferred method for batch-wise reactions	Highest throughput
	Lowest up front capital	Highest degree of repeatability	Lowest in process inventory
	Will work for almost any product	Faster cycle time	Best repeatability and efficiency
Cons	Slowest cycle times	Raw materials require bulk storage	Raw materials require bulk storage
	Highest operating expense	Large plant footprint	Will not work for all products
	More prone to human error		Least flexible

Batch blending

Manual batch blending (Figure 1) is the most flexible option and has the lowest capital cost. It is possible to make a wide array of mixtures and conduct a large number of reactions in the same tank using this approach. The main downsides are that manual batch blending is relatively slow and labor-intensive. Additionally, because operators weigh the raw materials, human error and variability are factors. To speed up the process and mitigate the risk of human error, automating a blending system is an option.

Automating a batch blending system involves higher capital costs, due to the added instrumentation, automated valves, programming and required bulk storage. Advantages include significantly reduced cycle times and manpower requirements, thereby increasing throughput and reducing operating expense. Changing a blending formulation can be straightforward if no new ingredients are required. Automated blending can offer a "sweet spot" between manual batch and continuous inline blending, in terms of costs and throughput.

Continuous blending

Continuous inline blending is almost always a fully automated process. It has major advantages over the previously mentioned methods, but is more restrictive with regard to the types of applications in which it can be employed. If properly sized, continuous blending equipment does not require mix tanks or final product storage. This allows for less in-process inventory, reduced working capital and plant footprint.

Continuous inline blending is also the least flexible of these options when it comes to recipe changes. Making small adjustments to the ratio of the ingredients is easy, but major changes cannot be made without hardware and software adjustments. This being said, with a clear vision of the desired end result, it is possible for a single inline blending system to be capable of making many different mixtures of coloring, fragrance or flavor as easily as selecting a new recipe.

Questions to consider

Each blending application has its own specific challenges to consider. Is there a minimum amount of time required for an additive to dissolve? Is the viscosity of the material too high for some methods? Is the heat of dissolution or reaction negligible or high enough that it must be carefully accounted for? Many factors must be considered and balanced for each individual application, and in many cases, it may be useful to consult an expert before settling on a solution. Hopefully, this information has your project headed in the right direction. ■

FIGURE 1. Manual batch blending offers the most flexibility, but also has the highest operating expense

Editor's note: Content for this Facts at your Fingertips column was provided by Stephen Benbrook, process development engineer at EPIC Modular Process Systems, Inc. (4242 Meramec Bottom Rd., St. Louis, Mo.; Phone: 314-272-4149; Website: www.epicmodularprocess.com; Email: sbenbrook@epicsysinc.com).

Diammonium Phosphate Production

By Intratec Solutions

Diammonium phosphate (DAP) ranks among the most important phosphate-based fertilizers, not only for its high nutrient content, but also for its excellent physical properties, such as high solubility and alkaline pH around the dissolving granules.

DAP is commonly formulated in a controlled reaction of phosphoric acid with ammonia. It is typically produced in both granular form, to be used as fertilizer either directly or blended with other types of fertilizers, and in nongranular form, to be used in liquid fertilizers.

The process

The following paragraphs describe a process for diammonium phosphate production from phosphoric acid and ammonia via an ammoniation-granulation process using a pipe reactor. Figure 1 presents a simplified flow diagram of the process.

Ammoniation-granulation. Initially, phosphoric acid, gaseous ammonia, and scrubber liquor are directed to the pre-neutralizer reactor. The main goal of the pre-neutralization is to form an ammonium phosphate slurry that will be sent to the pipe reactor downstream, in order to reduce the amount of water vaporized during granulation.

From the pre-neutralizer, the ammonium phosphate slurry is fed to the pipe reactor, along with additional phosphoric acid and gaseous ammonia. The pipe reactor is a horizontal reaction tube that is mounted inside a drum known as the granulator's drum.

The reaction mixture from the pipe reactor is sprayed onto the rolling bed of a rotary ammoniator granulator (the granulator). The slurry then reacts with additional liquid ammonia and recycled solids from sizing and crushing area. The diammonium phosphate granules formed in the granulator are discharged to the dryer downstream.

Drying, cooling and sizing. The DAP granules are dried with moderate heat at about 85°C. At this temperature, the wet fertilizer entering in the concurrent rotary dryer is not damaged by the hot air, while the moisture is gradually removed as the fertilizer passes through the drum.

The dried DAP granules are then distributed over screens to separate on-size material from the oversized and undersized particles. The undersized material is recycled to the granulator. The oversize material is sent to chain mills, where it is crushed and then recycled along with the undersize material.

The correctly sized granules are subsequently cooled by chilled air in a fluidized-bed cooler in order to achieve the storage temperature. Finally, DAP granules are packed in bags and stored in warehouses.

Scrubbers. A scrubbing circuit that comprises four scrubbers recovers the unabsorbed ammonia gases from pre-neutralizer, granulator, dryer and cooler. Phosphoric acid solutions are used in the scrubbers. The scrubber liquor, which contains the recovered ammonia, is recycled to the pre-neutralizer.

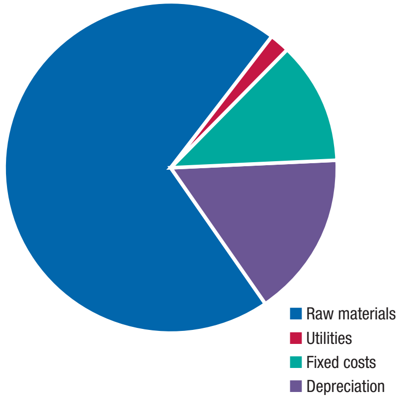


FIGURE 2. The pie graph shows the operating cost distribution

Economic performance

An economic evaluation of the process described was conducted on a plant with the capacity to produce 850,000 metric tons of DAP per year, based on data from the third quarter of 2013. The total operating cost (raw materials, utilities, fixed costs and depreciation costs) estimated to produce DAP was about $360 per ton of DAP. Figure 2 shows the total operating cost distribution.

This column is based on "Diammonium Phosphate Production – Cost Analysis," a report published by Intratec. It can be found at: www.intratec.us/analysis/diammonium-phosphate-production-cost. ■

Edited by Scott Jenkins

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

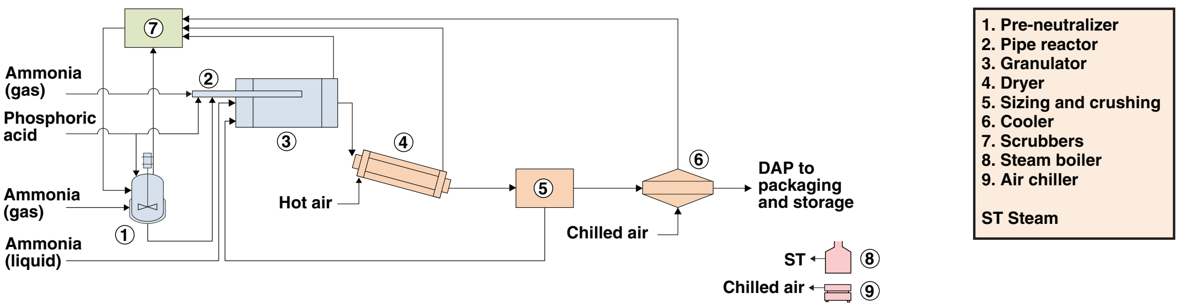


FIGURE 1. The process description shows a production process for diammonium phosphate

Reboiler Circuit Debottleneck with No Hardware Changes

With a thorough investigation and proper problem diagnosis, an entire gas plant limited by a deethanizer reboiler circuit was successfully debottlenecked

Henry Kister
Fluor Corp.

IN BRIEF

This article describes a case study of a gas plant (designed by others) that was bottlenecked by the reboil system of a deethanizer stripper. The reboiler system, which consisted of two parallel, once-through thermosiphon circuits, had experienced two different steady-state conditions. One condition had a good split of liquid to each of the two circuits, as is normally expected. However, when operated at relatively low rates, a second, undesirable steady state occurred, with maldistribution between the two circuits, in which one circuit was circulating while the other remained full of liquid. This steady state persisted when tower feed rates were raised until the circulating reboiler reached its heat transfer limitation, still with the other circuit full of liquid.

A variety of troubleshooting techniques — including pressure-drop calculations, close design reviews, examination of operating charts, and gamma scans — led to a correct diagnosis, which enabled debottlenecking of the reboiler circuits and the entire gas plant without any hardware modifications. The desired steady state was established by an operation that, for a short period, generated higher liquid circulation and pressure drop through the reboiler circuits. Once established, the desired steady state persisted when the operation was returned to normal.

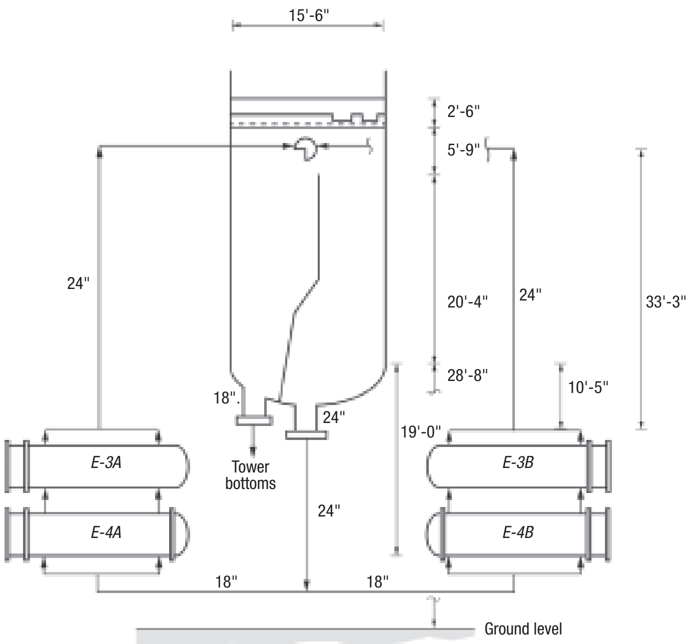


FIGURE 1. Shown here are the deethanizer stripper *A* and *B* reboiler circits. The lower reboiler in each circuit (*E-4A* or *E-4B*) is heated by hot naphtha, the upper reboiler (*E-3A* or *E-3B*) is heated by high-pressure steam

Important lessons

A review of this detailed case teaches some very important lessons, discussed below:

- With a parallel reboiler system, maldistribution between parallel circuits does occur and can cause severe bottlenecks (To the best of our knowledge, this is the first time that such maldistribution is reported in the literature).
- Pressure balances need to be considered at the design stage, not only for the maximum design rates, but also for the minimum expected operation rates
- It is important to provide flexibility in once-through reboiler systems that will permit operation as a circulating thermosiphon system, at least at low rates
- Good troubleshooting can provide low-cost (in this case, no-cost) debottlenecking of an entire gas plant

Process description

This newly built gas plant was bottlenecked by its deethanizer stripper. The tower bottleneck appeared in the reboiler circuit. In early April 2014, the author's company (which had no involvement in the tower or reboiler design, but has extensive experience in distillation design and troubleshooting), was requested to assist with investigating the root cause of the bottleneck and to find ways to overcome it.

A task force, including process and operation engineers from the operating company and Fluor's distillation specialists, was created. The joint team identified the root cause. Based on the root cause, a solution was successfully implemented. After this the deethanizer stripper and gas plant were returned to full operation, achieving the design rates. Described below is the troubleshooting investigation that was carried out, and the lessons learned.

The deethanizer stripper is a tower that is 15 ft, 6 in. in diameter. It is equipped with four-pass conventional valve trays with moving round valves. The tower base contains a preferential baffle that divides the bottom sump into a separate reboiler-draw compartment and a separate bottoms-draw compartment. Liquid leaving the bottom valve tray is diverted to the reboiler-draw compartment (Figure 1). From there it flows into a battery of four horizontal thermosiphon reboilers. The liquid from the bottom tray is diverted to the reboiler-draw compartment by notched-bottom seal pans.

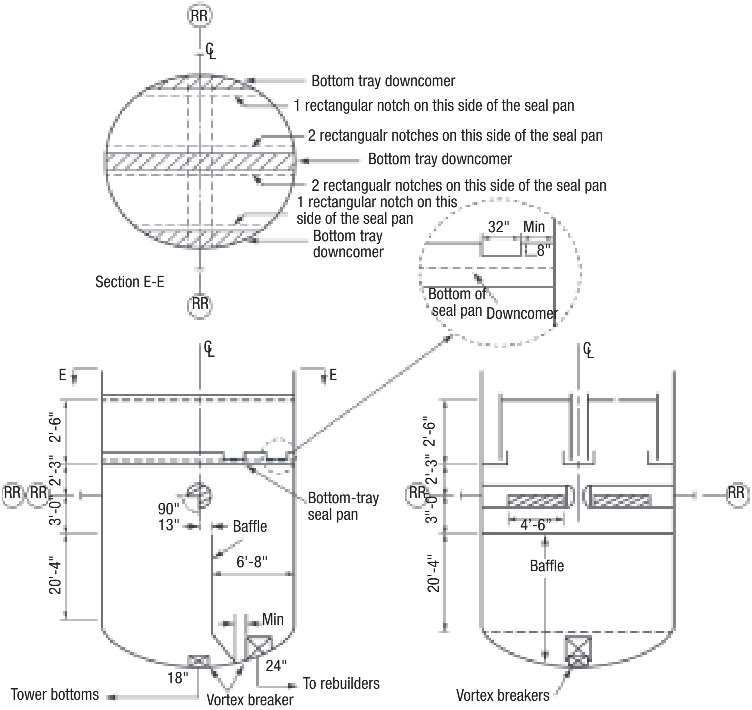


FIGURE 2. As part of the deethanizer stripper tower base geometry, a preferential baffle divides the tower bottom into a reboiler draw sump and a bottom product draw sump. All of the liquid from the trays is directed into the reboiler draw sump via a notch arrangement, while all the liquid returning from the reboilers is directed toward the bottom product draw sump via cutouts in the reboiler return pipes

As shown in Figure 2, the 8-in.-deep notches in the seal pans are located right above the reboiler-draw compartment. There are no notches above the bottom-draw compartment. The purpose is to feed all the bottom-tray liquid to the reboilers.

The vapor-liquid mixture returning from the thermosiphon reboilers enters above the bottoms-draw compartment via two opposite 24-in. nozzles. Each nozzle is equipped with a pipe that extends to close to the centerline of the tower and has a cutout that measures 4 ft, 6 in. in the bottom quadrant. Both cutouts are directed toward the bottoms-draw sump (Figures 1 and 2).

The purpose is to have all the reboiler-return liquid enter the bottoms-draw compartment, and to have none enter the reboiler-draw compartment. The vapor returning from the reboilers ascends to the bottom tray, while the liquid returning from the reboilers descends to the bottoms-draw compartment.

This design generates a once-through [1] thermosiphon reboiler system. Such a system intends to capture all of the liquid leaving the bottom tray and feed it directly to the reboiler. The reboiler-return liquid is entirely drawn as bottoms product. None of the reboiler-return liq-

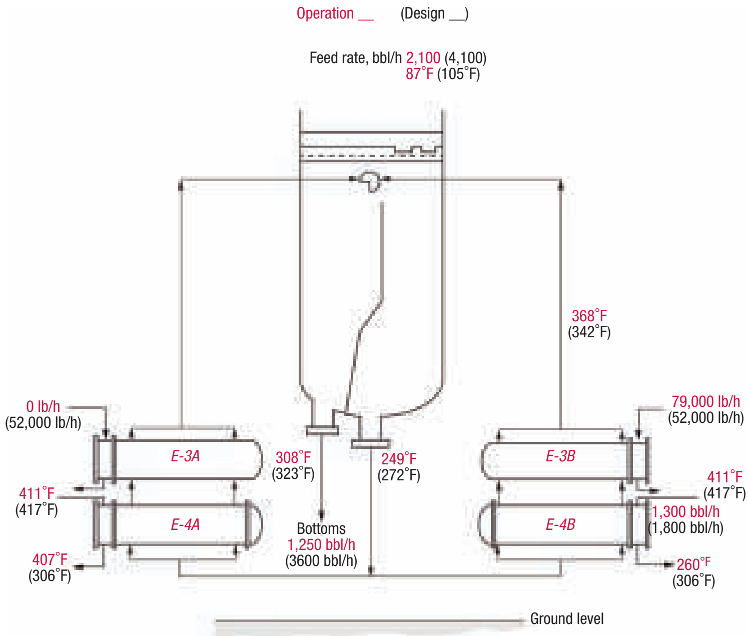


FIGURE 3. This figure shows the deethanizer stripper base, operation versus design. The zero-steam flowrate through *E-3A* and the absence of significant temperature difference across the heating side of *E-4A* indicate no boiling and no significant circulation through the *A* circuit

uid is recycled back to the reboiler — hence the name "once-through."

Once-through systems can achieve one full theoretical stage of separation, if the trapout tray and draw pan do not leak [*1*]. With the cold bottom-tray liquid being fed to the reboiler, it can also maximize the reboiler temperature difference and capacity. Reboil vapor is limited to about 40% of the bottoms-product rate, due to the normal limitation of 30% maximum vaporization (by weight) in thermosiphon reboilers [*1*]. This makes once-through thermosiphon systems appropriate only for low-boilup systems, such as strippers. Many deethanizer-strippers use once-through thermosiphon-reboiler systems.

This deethanizer stripper has four horizontal reboilers, arranged in two parallel circuits, *A* and *B* (Figure 1). In each circuit, the lower reboiler (*E-4A* or *E-4B*) is heated by hot naphtha liquid, while the upper reboiler (*E-3A* or *E-3B*) is heated by high-pressure steam. In each circuit, the naphtha and steam reboilers are designed to provide duties of 32 million Btu/h and 40 million Btu/h, respectively.

On the boiling side, liquid to the reboilers is provided from the reboiler-draw sump, via a 24-in. pipe that splits into two 18-in. pipes, each going to one circuit. The reboiler effluent from each circuit returns to the tower via a 24-in. line.

Initial performance

During the startup, the plant was at low rates and to improve tower stability, it was decided to take the steam out of reboiler *E-3A*. This was successful at creating a steady steam flow through the *E-3B* reboiler circuit and provided tower stability, but the plant has been unable to re-establish flow through the *E-3A/E-4A* set of reboilers ever since. For the next six months or so, the *E-3B/E-4B* circuit did all the reboiling, while the deethanizer-bottoms liquid circulation had been difficult to establish through the *E-4A/E-3A* circuit.

Figure 3 shows typical operating data from six months after start up and compares them to the design values. The zero-steam flowrate through *E-3A* and the absence of significant temperature difference across the heating side of *E-4A* indicate no boiling and no significant circulation through the *A* circuit. To maximize duty, steam to *E-3B* was raised to the maximum, well above the design steam rate for this exchanger, but still not high enough to make up the lost duty of *E-3A*. This restricted the feed flowrate through the tower and bottlenecked the entire gas plant. There was a need to get the stripper-bottoms liquid to start flowing through the *E-4A/E-3A* circuit.

Troubleshooting

Initial troubleshooting efforts focused on initiating flow through the *A* circuit by inducing a gas lift. One possibility was that the light components were stripped out of the *A*-circuit reboilers, leaving behind heavy hydrocarbon liquid. Heating this heavy liquid may not have produced enough vapor to initiate reboiler action. Injecting a light gas, such as nitrogen, could possibly gas-lift the heavy liquid and initiate thermosiphon circulation. This technique has been successful in the past for initiating circulation in liquid-full thermosiphon reboilers [*2–4*].

A source of nitrogen was connected to a bleeder valve immediately downstream of *E-3A*. Nitrogen was injected for 4–6 hours in an attempt to provide lift and jump-start the thermosiphon effect. This action was unsuccessful in initiating circulation through the *A* circuit.

This came as a surprise, as in other reboilers [*2–4*], a similar action had been successful. There were questions as to whether enough nitrogen was applied, whether it was applied at the correct point, and whether the liquid in the reboilers was just too heavy and needed to be drained and replaced by fresh liquid before the gas lift attempt. Addressing these problems would have required some painful modifications or operations with no assurance of success. The validity of the theory — that heavy liquids in the *A*-circuit are the root cause — was questioned. With these considerations in mind, the investigation team decided to perform more troubleshooting before trying out a fix.

One useful reference point was process data from the very initial operation of the stripper. The operating charts from shortly after initial start up (Figure 4), at a stripper feedrate of about 1,700 barrel per hour (bbl/h), show both the *A* and *B* circuits operating simultaneously and stably. Both *E-3A* and *E-3B* reboilers operated stably with a steam flowrate of about 32,000 lb/h to each. For both the *E-4A* and *B* reboilers, the temperatures of naphtha entering and leaving were about 400°F and 320°F, respectively. At time 22:40 hours, the stripper feedrate plunged, steadying at about 1,200 bbl/h 40 minutes later.

To improve stability, the plant manually reduced the steam flowrate to *E-3A*, to about 8,000 lb/h, with the steam rate to *E-3B* remaining at its previous value. The naphtha temperatures into and out of *E-4A* became the same, about 360°F,

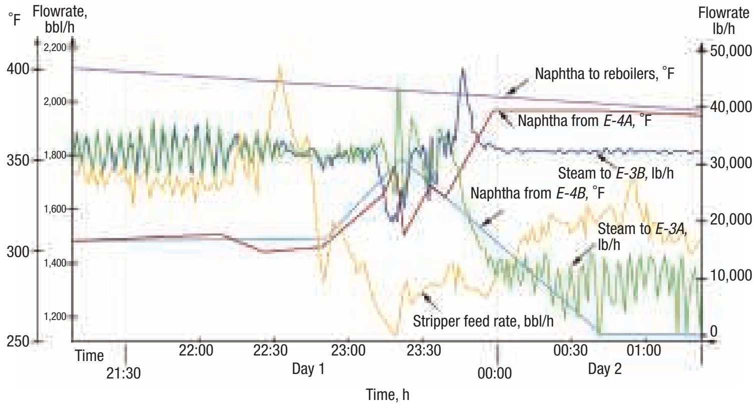


FIGURE 4. Shown here are the process data for the very initial operation of the stripper-reboiler circuits. Before 23:00 hours, both circuits operated simultaneously and stably with the same steam flows and naphtha temperature differences for each circuit. After 0:00 hour, the steam rate to *E-3A* dropped and the temperatures of naphtha entering and leaving *E-4A* became the same, suggesting boiling and circulation in the circuit had stopped

suggesting it had stopped heating.

At the same time the temperature outlet from *E-4B* decreased to about 260°F, suggesting that this reboiler was working harder than before. Both of these occurrences suggest that the *A*-circuit stopped circulating. Early on the next day, the feedrate to the stripper rose again, to 1,500 bpl/h, but this time the *A* circuit remained inactive. It was common practice to attempt to restart circulation by opening and closing the steam valve on the stalled set, but circulation remained stalled.

This sequence of events suggests the possibility of the existence of two hydraulic steady states, with an easy switchover from one to the other. This is likely to take place when the reboiler pressure drop on the boiling side is low.

Pressure drop

Calculations performed during the design by the engineering contractor that designed the circuits showed a total pressure drop of 1 psi for the exchangers in each circuit at design conditions. The contractor's calculated pressure-drop values were 0.4 psi and 1.3 psi for the reboiler-liquid inlet line and the reboiler-return lines, respectively. The total pressure drop is equivalent to 11 ft of liquid head.

Figure 1 shows the elevations of the reboiler circuits. The diagram shows that not much liquid head is required to overcome the pressure drop in the reboiler circuit. The liquid level in the reboiler draw compartment will therefore be near the bottom of the compartment, even at the design rates.

At the low rates, the pressure drop will be lower still, and the liquid level will drop further, possibly dropping out of the reboiler-draw compartment into the reboiler-liquid-inlet pipe. Further, at low boilup rates the bottom tray may weep, sending liquid directly into the bottom draw compartment, and causing the liquid level to be lower still.

At a low liquid head, fluids tend to form their favorite flow patterns. Two steady states can form:

- One with operation of the two reboilers simultaneously, as intended
- The other has all the boiling taking place in one circuit, and the other circuit filling with liquid to the same height as the liquid in the reboiler liquid inlet pipe

Once the latter steady state forms, the steam that is still going in (the 8,000 lb/h going to *E-3A* after midnight on the second day, as shown in Figure 4) , will strip the lights out of the near-stagnant liquid. Before long, heavy liquid will form in this circuit, and this liquid will be difficult to boil. This situation will stabilize this steady state and it will persist.

The proposed theory states that the liquid level in the reboiler compartment would be very low, possibly absent, and will not approach the overflow baffle. This can be easily tested using gamma scans. The tower base was gamma scanned, both on the bottom compartment side and on the reboiler compartments side. In addition, neutron-backscatter scans were performed to confirm or deny the gamma scan results.

The gamma and neutron scans showed the following:

- Nothing abnormal showed up on the inner active area scans for the bottom six trays. Other trays were not scanned
- Both the gamma and neutron scans showed that the liquid level in the bottoms-draw compartment was 10–12 ft above the tangent line. This was the same as the level indicated by the level instrument
- Both gamma and neutron scans had difficulty finding a liquid level on the reboiler-draw compartment. There definitely was no liquid level above the bottom tangent line. The gamma scans showed some absorption at the tangent line, about the same absorption as the froth on the trays, but this could have been due to the welds at the tangent line. The neutron scans showed no liquid at all in the reboiler-draw compartment

The absence of liquid level in the reboiler-draw compartment gave strong support to the "two steady-states" theory.

Solution

With the theory verified, the challenge was now shifting from the steady state with the stagnant *A* reboilers, back to that of the two reboiler circuits operating simultaneously.

In a circulating thermosiphon reboiler (as distinct from a once-through thermosiphon, such as the stripper reboilers), increasing the liquid head in the tower base generates more liquid circulation through the reboiler circuit and reduces the fractional vaporization [*4*]. Considering the pressure balance and assuming a constant heat duty, the higher liquid head supplied to the reboiler is matched by the additional friction head due to the enhanced liquid circulation rate plus the additional static head due to a higher amount of liquid in the reboiler shell and outlet line.

Extending this reasoning to the stripper reboilers, generating liquid circulation and increasing the liquid head in the reboiler-draw compartment will raise the pressure drop through the active reboiler circuit. This higher pressure drop will induce some of the liquid to follow the easier path (that is, the path with less pressure drop) through the inactive reboiler. Once this liquid is heated, it will start boiling, and the thermosiphon will be established in the previously inactive circuit.

One way to generate circulation and increase the level in the reboiler-draw compartment is to raise the level in the bottom-draw compartment until it overflows the baffle, and keep the bottom-draw compartment full during the circulation. The risk is that the liquid level may ascend to the trays and cause flooding and possible damage there. It is important to avoid excessive buildup of liquid up the tower.

In principle, the level transmitter can be watched during the operation to avoid excessive liquid level. This was difficult in this deethanizer stripper. Since the reboiler-return pipe is only 2 feet above the baffle (Figure 2), and the vapor from the reboiler return blows downward, causing a frothy dispersion, the frothiness may reduce the specific gravity and lead to an optimistically low level measurement. Also, the high tap of the level transmitter is just less than 2 feet above the baffle, which may make it difficult to see when the level rises toward the trays. Fortunately, there is a differential-pressure transmitter across the stripper that comes from the upper tap of the level transmitter and therefore can monitor any accumulation of liquid above the upper tap.

The plan was to raise the liquid level in the bottoms-draw compartment to the level of the reboiler return, an increase in height of about 20 ft. When the level was first raised, it was controlled using the differential-pressure transmitter. Subsequently, a pair of electronic pressure gages was added to the reboiler side of the column to monitor the level directly, and an additional gage was added to the product outlet line to monitor the level on the bottoms-draw side of the baffle. In order to avoid damage due to entrainment of liquid through the trays the differential pressure across the bottom trays was closely monitored.

To raise the level on the reboiler side of the baffle, the bottoms-draw side liquid was overflowed to the reboiler side, by reducing the bottom-product flowrate. The level rose until it reached the top of the baffle when it "flat lined" as it overflowed.

After one hour of overflowing the baffle, the level had increased on the reboiler side by 13 ft. At that time, the following two process indications provided evidence that the *A* side reboilers were starting to circulate liquid:

1. A rapid decrease in steam consumed by the *3B* reboiler suggested a decrease in liquid flow to the *B* side reboilers; and
2. A rapid decrease in *4A* hot-side outlet temperature suggested an increase in duty in the *4A* reboiler

bypasses the reboiler side of the baffle. The bottom tray is an active tray. It remains unclear whether the tray weeps enough liquid to cause the problem, or whether some of the liquid directed to the reboiler-draw side of the baffle falls into the bottoms-draw side of the tower base. To fix this in the future, the bottom tray will be replaced with a total trapout tray to ensure all bottoms liquid must pass through the reboilers.

Until the plant gets to an opportunity to install the chimney tray, the reboiler continues to stall periodically, so raising the liquid level has become a standard procedure that has been executed several times since by the operations team, to regain lost reboiler circulation.

Lessons learned

The investigation described here highlights the importance of good troubleshooting and problem diagnosis for overcoming bottlenecks. In our case, pressure-drop calculations, close design reviews, detailed examination

At low pressure drops, parallel once-through thermosiphon circuits may switch from their intended steady-state with even split between the circuits to an unintended steady-state with uneven split between the circuits. Reduced heat transfer and/or instability may result.

Steam was quickly opened to *3A* to ensure we maintained *A* side reboiler circulation. Almost immediately, even split and duties were confirmed between the *A* and *B* side reboilers. The bottoms-outlet flow was increased to stop overflowing the baffle, and the bottoms level was returned to normal.

The 13-ft level increase was probably not enough to get the level of weathered liquid (the liquid that was sitting in the A reboiler circuit for a lengthy period) up to the reboiler-return nozzle on the tower. But the fresh liquid that had entered the reboiler as the level was being raised provided enough vaporization to gas-lift the weathered naphtha into the tower and start the circulation.

The column remains prone to losing reboiler duty. This is believed to be because a portion of the bottom-tray liquid

of operating charts, and conducting gamma scans led to the correct diagnosis, which enabled debottlenecking an entire gas plant with no hardware modifications.

Maldistribution between parallel reboiler circuits has received little attention in the literature, with no published case studies identified by Kister's survey [*2*]. To the best of our knowledge, this is the first time this type of experience has been reported. This maldistribution is especially severe at low rates, when the pressure drops in the reboiler circuits are low. Due to the low pressure drop, the fluids find their favorite pathways and steady states, and can easily swing from one steady state to another — promoting instability. With parallel reboiler circuits, careful analysis of the pressure balance both at the normal-and reduced-rate operation is important, and should be performed at the design stage. This case demonstrates that increasing the pressure drop in these circuits can help route the fluids to the preferred pathways and counter this maldistribution.

Baffled systems have their benefits [*1*], but can also generate or amplify hydraulic problems; thus they need to be designed carefully. In the case of the deethanizer stripper, the baffle was far taller than it needed to be. Had it been even a couple of feet shorter, it would have been easy to raise the liquid level in the bottoms compartment above it and achieve better operational flexibility.

It is important to provide flexibility when designing once-through thermosiphon circuits. As pointed out [*1,2,4*] they can be quite troublesome, and adding simple features that can convert them temporarily to circulating thermosiphon circuits can go a long way toward easing startups and avoiding process bottlenecks. ■

Edited by Suzanne Shelley

References

1. Fractionation Research Inc., Design Practices Committee, Reboiler Circuits for Tray Columns, *Chem. Eng.*, January 2011, p. 26.
2. Kister, H.Z., "Distillation Troubleshooting," Wiley-Interscience, 2006.
3. Kister, H.Z., T.C. Hower, Jr., P.R. de M. Freitas, and J. Nery, "Problems and Solutions in Demethanizers with Interreboilers," *Proc. 8th Ethylene Producers Conf,*. New Orleans, La., 1996.
4. Kister, H.Z., "Distillation Operation," McGraw-Hill, N.Y., 1990.

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Dry-Tray Pressure Drop of Sieve Trays Revisited

Data points from literature are refined into a single correlation defining dry-tray pressure drop in sieve trays

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Sulzer Chemtech USA

Tony J. Cai
Fractionation Research, Inc.

IN BRIEF

DEVELOPING THE FOUNDATION

AN UPDATED EQUATION

The sieve tray has been in the marketplace as a distillation device for many decades. It has been used extensively on distillation tray equipment worldwide as a highly efficient vapor- and liquid-contacting device (Figure 1). Many people have previously examined dry-tray pressure drop data for sieve tray decks, including the authors of this article. Ref. 1 is an article correlating the data from literature into an equation. However, Ref. 1 leaves the "door open" for additional refinement of this correlation for those applications that might have high ratios of tray thickness (*TT*) to hole diameter (*Dp*) — for instance, tiny-hole applications in aluminum, as has been practiced in air separations processes. Ref. 2 is a recent presentation on this subject, covering the use of computational fluid dynamics (CFD) for very thick trays. This article combines Refs. 1 and 2 into a single definitive correlation for the dry-tray pressure drop of sieve trays. An improved correlation with the proper functionality for the dry-tray pressure drop of sieve trays is presented here. It incorporates the effects of tray thickness, sieve-hole diameter and open area, and is compared to experimental data.

FIGURE 1. Sieve trays are frequently used in distillation operations due to their efficient liquid and vapor contacting capabilities

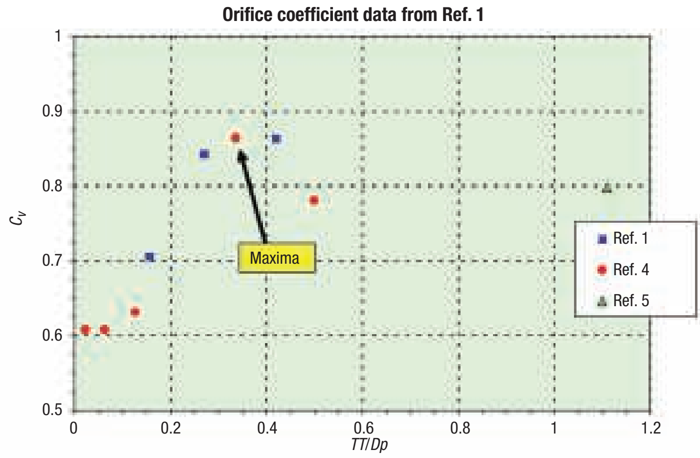
Developing the foundation

As was stated in Ref. 1: "Dry-tray pressure drop is an extremely important hydraulic parameter that aids the tray designer in many different ways. Obviously, it is one of the major contributing parameters in the overall tray pressure drop. But more importantly, its magnitude can tell an experienced designer whether he or she is near flood, is at turndown, has a stable tray, or may be approaching spray fluidization. Finally, it can be used to understand the overall behavior/performance of a tray. Dry-tray pressure drop is a fundamental building block of most other hydraulic parameters and its accuracy (or inaccuracy) has far-reaching consequences."

The dry-tray pressure drop hydraulic parameter is quite a simple concept. For fixed-opening devices, the dry-tray pressure drop can be reduced from Bernoulli's principles and takes on the form of Equation (1) below.

$$\Delta P_{dry} = 12\rho_V (V_H/C_v)^2 / (2g_C\rho_W) \quad (1)$$

FIGURE 2. Data from Ref. 1 necessitated the creation of a maxima in the development of the pressure-drop correlation, but other data did not support this conclusion



Where:
ΔP_{dry} = Dry-tray pressure drop, in. of water
V_H = Hole velocity, ft/s
ρ_V = Vapor density, lb/ft^3
C_v = Hole (orifice) discharge coefficient
ρ_W = Water density, 62.4 lb/ft^3
g_C = Acceleration of gravity, 32.2 ft/s^2

If one combines all the constants from Equation 1 into a single constant *Cp*, the equation becomes simplified, as shown in Equations (2) and (3).

$$\Delta P_{dry} = Cp\,(V_H^2)\,\rho_V \quad (2)$$

$$Cp = 1/(334.76\,C_v^2) \quad (3)$$

The previous work in Ref. 1 defined a new correlation to handle the complexities of *Cp* with respect to open area, tray thickness and hole diameter. However, two data points forced the author to make the correlation have a maxima at a *TT/Dp* ratio of about 0.35, as seen in Figure 2. This maxima was never discovered or observed previously by anyone dealing with this topic.

With the presentation of Ref. 2, it became obvious that this maxima

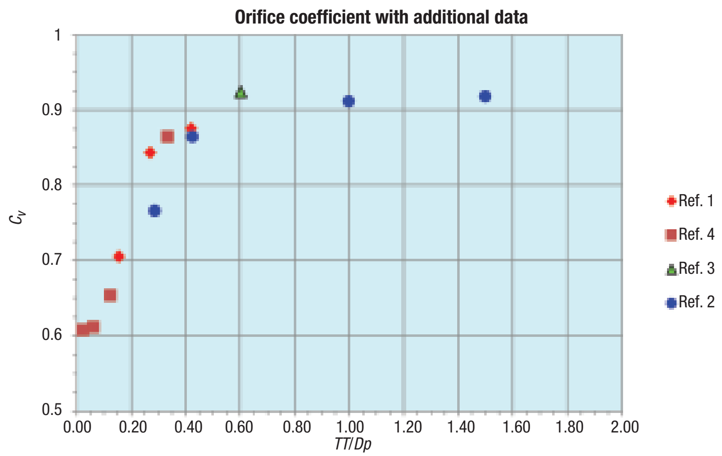


FIGURE 3. The consideration of additional literature data led to the sigmoidal function shown here

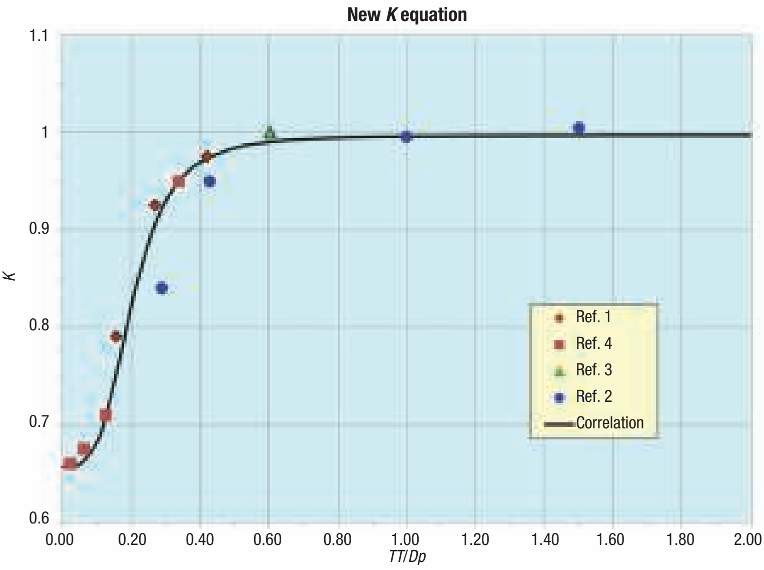
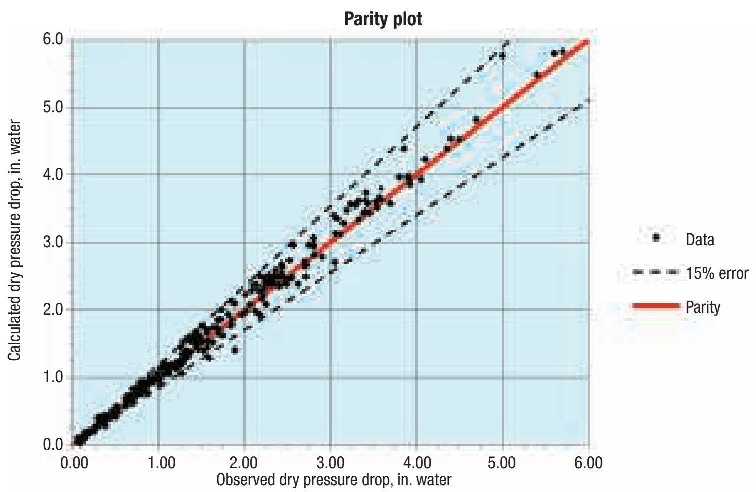


FIGURE 4. A comparison of literature data with the correlation for the open-area effect on orifice coefficients (*K*) given in Equations (4) and (5) shows a good fit

FIGURE 5. The new correlation compares well with experimental data from literature



was incorrect. Figure 3 shows the data from both Ref. 1 and Ref. 2. One can readily see that a different correlation (with no maxima) needed to be developed.

First, however, the two "extraneous" data points from Ref. 1 needed to be dispelled. The first is the rightmost data point from Fractionation Research Inc. (FRI; Stillwater, Okla.; www.fri.org) shown in Figure 2. This is a 1959 data point from Run no. 36 of Ref. 4 and cannot be reproduced today. Since then, FRI has made a number of dry-tray pressure drop measurements in a simulator with thicker trays [*3*], and as a result, the authors can no longer support this data point. The work in Ref. 3 is proprietary to FRI until 30 years after the report is written. The other data point is from Ref. 5, and the authors discovered that this point is for smooth openings and was operated at very low Reynolds numbers. Again, this data point cannot be supported. Therefore, Figure 3 has purposefully omitted these two data points.

The new curve is now a typical sigmoid function that has the classic "S" shape [*6*]. Selected dry-tray pressure drop data used in the development of the new dry-tray pressure drop correlation [*2*, *3*, *4*, *7*] are summarized in Appendix 1, which is available with the online version of this article at www.chemengonline.com. For the purposes of this article, FRI has allowed the use of one of the data points from Ref. 3 that helps to "fill in the gap" at a *TT/Dp* ratio of 0.6.

An updated equation

As was used in Ref. 1, the open-area effect on the orifice coefficient is reflected in the term *K*, as defined in Equation (4) and first established by Kolodzie and Van Winkle [*8*]. The current authors found no data to support the need for any revision to this equation. However, the *K* equation itself needed to be updated. The new form of the sigmoidal *K* equation is given by Equation (5).

$$K = C_V\,(Dp/P)^{-0.10} \quad (4)$$

$$K = 0.997 - \{0.34/[1.0 + (4.925\,TT/Dp)^{3.582}]\} \quad (5)$$

Where:
Dp = Hole diameter, in.
TT = Tray thickness, in.
P = Pitch (center-to-center distance between holes), in.

This equation, when compared to the data collection, is shown in Figure 4. This equation is only good for hole Reynolds numbers greater than 4,000. For most applications this will be true. Keep in mind, however, that when the hole Reynolds number is low, the dry-tray pressure drop is also very low and the accuracy of its value becomes insignificant in comparison to the total tray pressure drop.

Applying the improved *K* equation to the aforementioned data, and limiting those data to open areas that are 20% or less of the active area, Figure 5 was generated. This figure clearly shows that the improved correlation is accurate by keeping the data points within a reasonable error band.

In conclusion, an improved and definitive equation for dry-tray pressure drop in sieve trays is generated. This equation matches, with mean absolute relative error of 10.6%, data from four different sources. This equation can be used for all commercial sieve-tray applications, provided that the holes are punched from the top in the downward direction. ■

Edited by Mary Page Bailey

See the online version of this article at www.chemengonline.com to view the data in Appendix 1.

References

1. Summers, D.R., Dry Tray Pressure Drop of Sieve Trays, *Chem. Eng.*, June 2009, pp. 36–39.
2. Li, X.P., Whiteley, J.R., Resetarits, M.R. and Cai, T.J., CFD Simulation of Thick Sieve Tray Dry Tray Pressure Drops, 2015 AIChE Spring Meeting, Kister Distillation Symposium, paper 206a.
3. Cai, T.J. and Resetarits, M.R., Thick Sieve Tray Dry Pressure Drops, FRI Topical Report No. 195, 2013.
4. Clark, D.K. and Miller, J.D., FRI Topical Report No. 20, Oct.1959.
5. Biddulph, M.W and Thomas, C.P., Effect of Liquid Surface Tension on Small Hole Distillation Sieve Tray Pressure Drop, *AIChE Journal*, Vol. 41, No. 4, pp. 819–827, 1995.
6. Von Seggern, D., "CRC Standard Curves and Surfaces with Mathematics, 2nd ed. Boca Raton, Fla., CRC Press, 2007.
7. Sulzer Chemtech Laboratory Data 1993–1998, proprietary information.
8. Kolodzie, P.A. and Van Winkle, M., Discharge Coefficients through Perforated Plates, *AIChE Journal*, Vol. 3, pp. 305–312,1957.

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Mixing: Impeller Performance in Stirred Tanks

Characterizing mixer impellers on the basis of power, flow, shear and efficiency

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Philadelphia Mixing Solutions Ltd.
Gustavo Padron and David A. R. Brown
BHR Group

IN BRIEF

TURBULENCE
IMPELLER GEOMETRIES
HYDRAULIC EFFICIENCY
SHEAR
PROCESS RESULTS
TRAILING VORTEX
APPLICATIONS
CONCLUSIONS

Mixing has been defined as "the application of mechanical motion in order to create fluid dynamic effects that achieve a desired process result" [*1*]. The process result is the objective of the vessel operator and will be a transformation of the ingredients fed to the vessel into a product. The goal of the equipment supplier will be to understand the role of mixing in promoting the transformation and choosing an impeller that will create the appropriate fluid-dynamic effects to do this.

Processes carried out in stirred tanks can be generally divided into the following two classes:

- Those relying on flow generated by the impeller creating motion throughout the fluid, such as blending of pigments into a resin or emulsion in paint manufacture where homogeneity of the vessel contents is critical to product quality
- Those relying on "shear" to reduce the size of a second dispersed phase, whether gas bubbles, liquid droplets or particles, such as a hydrogenation reactor where smaller bubbles provide more surface area for mass transfer from the gas into the liquid phase

Impellers are often described qualitatively as, among others, high flow, high shear or high efficiency, and the choice of equipment required to achieve the process result most efficiently is made on this vague basis. This article describes how the performance characteristics of impellers commonly used in stirred tanks can be quantified, thereby enabling engineers to make educated decisions about which ones to use in order to achieve their desired process results.

Turbulence

Turbulent flow is characterized by the presence of random fluctuations in velocity, so-called eddies, that are superimposed on the mean, time-averaged flow. There will be a

NOMENCLATURE

A Constant in Equation (30)
A_{DIS} Discharge area for primary flow from impeller
D Impeller diameter
d_{32} Sauter mean droplet size
Fl Flow or pumping number (= $Q/(ND^3)$)
K Ratio (= $\varepsilon_{MAX}/\bar{\varepsilon}$)
k_{MAX} Maximum kinetic energy in trailing vortex
l_0 Diameter of trailing vortex
N Impeller rotational speed
P Power
Po Power number [= $P/(\rho N^3 D^5)$]
Q Flow rate generated by impeller
R Impeller radius
r Radial position in impeller discharge for estimating velocity gradient
Re Impeller Reynolds number (= $\rho ND^2/\mu$)
T Vessel diameter
$\bar{U}$ Mean velocity in impeller discharge (= Q/A_{DIS})
V_{TIP} Impeller tip speed
v_H High velocity in impeller discharge for estimating velocity gradient
v_L Low velocity in impeller discharge for estimating velocity gradient
w Projected blade height
x Ratio of impeller to trailing vortex diameters (= D/l_0)
y Distance (in definition of shear rate)
α Constant (= v_H/V_{TIP})
β Constant (= v_L/V_{TIP})
$\dot{\gamma}$ Time-averaged velocity gradient
$\bar{\varepsilon}$ Power input per mass of fluid in vessel
ε_{MAX} Local energy dissipation rate in trialing vortex
η Efficiency defined as mass of fluid pumped per unit energy input by impeller
Λ Shear rate constant
ρ Liquid density
ϕ Efficiency defined as kinetic energy of fluid divided by mechanical energy input by impeller
ψ Constant (= r_H/R)
ω Constant (= r_L/R)

Subscripts
AX Axial
HYDFL Hydrofoil
IMP Impeller
HYDR Hydraulic
MECH Mechanical
PBT Pitched-blade turbine
RD Radial
RUSH Rushton

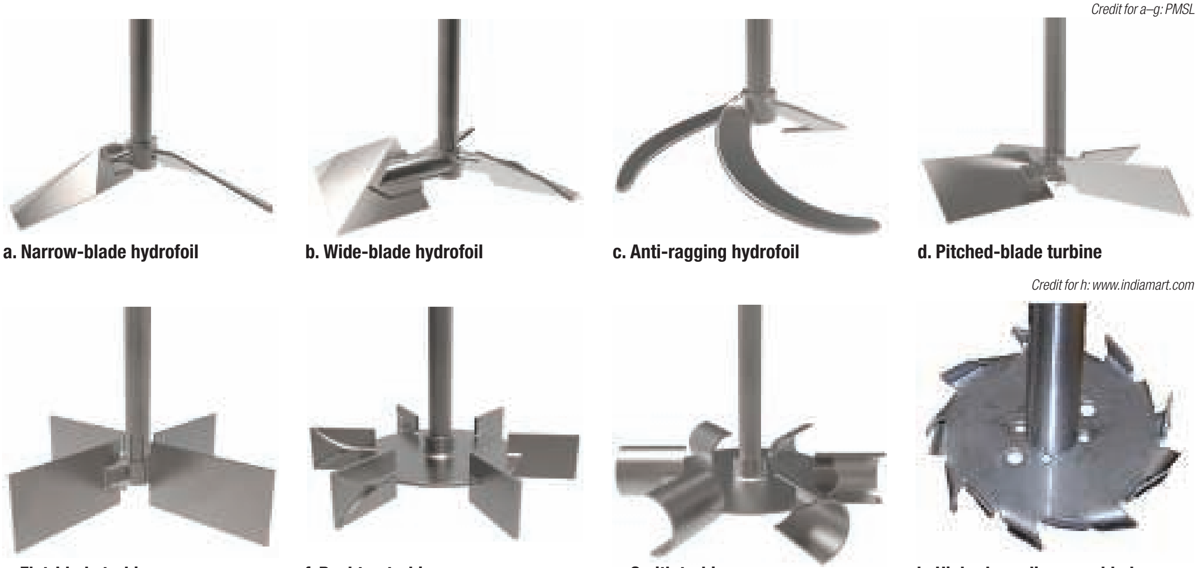

FIGURE 1. Four general classes of impellers are used in stirred tanks operating at low to medium viscosities in the turbulent regime. These impellers primarily generate: axial flow (a, b, c); mixed flow (d), radial flow (e, f, g) or dispersion or de-agglomeration (h)

range of eddy time and length scales associated with a particular flow field. The size of the largest eddies will be on the order of the size of the equipment generating the flow (for example, the blade width of an impeller). The size of the smallest eddies is the Kolmogorov length scale. The eddies also have a lifetime, with the larger eddies existing for a longer period than the small ones. Understanding the role turbulence plays in mixing processes is critical to successful design and scaleup [*2*].

Impeller geometries

There are four general classes of impellers used in stirred tanks operating in low to medium viscosity fluids in the turbulent regime (Re > 10^4):

1. Axial flow. The primary flow generated by an axial-flow impeller is directed down toward the base of the vessel. Hydrofoils with narrow or wide blades are in this category.

Hydrofoils have profiled blades that may be narrow like an airplane wing (Figure 1a) or wide like a marine propeller (Figure 1b). These impellers were developed to generate the same velocity profile as a propeller, but to be fabricated rather than cast to reduce the impeller's weight and cost. They are also easier to install since they can be supplied as a hub and blades that are assembled inside the vessel [*3*]. These impellers are generally considered to be "low-shear" [*4*].

An anti-ragging hydrofoil (Figure 1c) is used in wastewater applications. It has blades that are swept-back preventing build-up of fibrous matter, which is commonly present in municipal wastewater, on the leading edge of the blades.

2. Mixed flow. These impellers generate both axial and radial components of velocity and the distribution between the two can be controlled by adjusting the impeller diameter to vessel diameter ratio. Pitched-blade turbines (Figure 1d) are in this category.

Pitched-blade turbines have flat blades that are usually angled at 45 deg, although shallower and steeper angles are sometimes used.

3. Radial flow. These impellers generate a strong radial component of velocity directed at the vessel wall. A pitched blade turbine with 90-deg blade angle generates radial flow and is commonly called a flat-blade turbine (Figure 1e).

Impellers used for processes requiring dispersion of gas bubbles also generate a primarily radial flow, but have blades attached to a disk. The Rushton (Figure 1f) and Smith (Figure 1g) turbines are commonly used for these processes. The disk ensures that bubbles fed into the vessel beneath the impeller must flow through the blades where the local "shear" breaks them up, creating high interfacial area for mass transfer. The Rushton turbine is generally considered to be "high-shear" [*4*].

4. High-speed dispersers. These impellers look like circular-saw blades with alternating teeth angled up and down (Figure 1h). They operate at high rotational and tip speeds and are used almost exclusively for processes that require significant size reduction, such as dispersion and de-agglomeration of dry powder when preparing a slurry from liquid and a dry powder.

Hydraulic efficiency

Impellers in stirred tanks are machines that move fluid; essentially they are pumps. Like pumps, their efficiency can be defined and calculated. The hydraulic efficiency of a pump is the ratio of the kinetic energy of the flowing fluid to the mechanical energy input by the impeller.

The mechanical power input by an impeller in a stirred vessel is calculated from the following equation (Note: all nomenclature are defined in the box on p. 46):

$$P_{MECH} = Po \cdot \rho \cdot N^3 \cdot D^5 \quad (1)$$

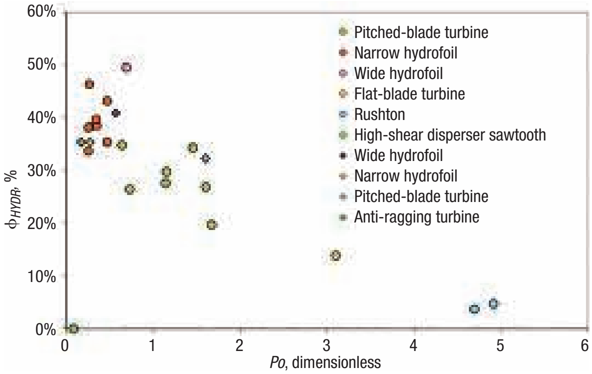

FIGURE 2. This graph plots the hydraulic efficiency, ϕ_{HYDR}, versus the power number for various impellers

Po is the impeller's power number and it is a drag coefficient that is determined by the geometry of the impeller (blade width, blade angle, number of blades and so on.).

The primary flow generated by an impeller is calculated from Equation (2):

$$Q = Fl \cdot N \cdot D^3 \quad (2)$$

Fl is the impeller's flow, or pumping number.

Both the power and flow numbers are measured experimentally and typical values for commonly used impellers are given in Table 1.

The average velocity in the impeller discharge can be calculated from Equation (3):

$$\overline{U} = \frac{Q}{A_{DIS}} \quad (3)$$

A_{DIS} is the area through which the primary flow is pumped. For axial-flow impellers, this is a disk with diameter equal to the impeller diameter and for radial-flow impellers it is the wall of a cylinder with diameter equal to the impeller diameter and height equal to the blade width.

For axial-flow impellers:

$$\overline{U} = \frac{Fl \cdot N \cdot D^3}{\left(\pi/4\right) \cdot D^2} = \frac{4Fl}{\pi} \cdot N \cdot D \quad (4)$$

For radial-flow impellers:

TABLE 1. TYPICAL VALUES OF *Po*, *Fl* AND *x* FOR COMMON IMPELLERS

Impeller	Power number	Flow number	$x = D / l_0$
Narrow-blade hydrofoil	0.30	0.52	17
Wide-blade hydrofoil	0.70	0.66	
Pitched-blade turbine	1.50	0.80	16
Flat-blade turbine	3.00	0.80	
Rushton turbine	5.00	0.65	12
HSD-Sawtooth	0.10	0.05	12

$$\overline{U} = \frac{Fl \cdot N \cdot D^3}{\pi \cdot w \cdot D} = \frac{Fl \cdot D}{\pi \cdot w} \cdot N \cdot D \quad (5)$$

The energy dissipation rate, or power, of the flowing fluid is the product of the flowrate and the head that the pump develops:

$$P_{HYDR} = Q \cdot \Delta H \quad (6)$$

Where:

$$\Delta H = \rho \cdot \frac{\overline{U}^2}{2} \quad (7)$$

Combining Equations (2), (4), (6) and (7), for axial flow impellers:

$$P_{HYDR} = Fl \cdot N \cdot D^3 \frac{\rho}{2}\left(\frac{4Fl}{\pi} \cdot N \cdot D\right)^2 = \frac{8Fl^3}{\pi^2} \cdot \rho \cdot N^3 \cdot D^5 \quad (8)$$

$$\phi_{AX} = \frac{P_{HYDR}}{P_{MECH}} = \frac{8}{\pi^2} \cdot \frac{Fl^3 \cdot \rho \cdot N^3 \cdot D^5}{Po \cdot \rho \cdot N^3 \cdot D^5} = \frac{8}{\pi^2} \cdot \frac{Fl^3}{Po} \quad (9)$$

Similarly, combining Equations (2), (5), (6) and (7), for radial-flow impellers:

$$P_{HYDR} = Fl \cdot N \cdot D^3 \cdot \frac{\rho}{2} \cdot \left(\frac{Fl \cdot D}{\pi w} \cdot N \cdot D\right)^2 = \frac{Fl^3}{2\pi^2} \cdot \left(\frac{D}{w}\right)^2 \cdot \rho \cdot N^3 \cdot D^5 \quad (10)$$

$$\phi_{RD} = \frac{P_{HYDR}}{P_{MECH}} = \frac{1}{2\pi^2} \cdot \left(\frac{D}{w}\right)^2 \cdot \frac{Fl^3 \cdot \rho \cdot N^3 \cdot D^5}{Po \cdot \rho \cdot N^3 \cdot D^5} = \frac{1}{2\pi^2} \cdot \left(\frac{D}{w}\right)^2 \cdot \frac{Fl^3}{Po} \quad (11)$$

The hydraulic efficiency, ϕ, is plotted against the impellers' power numbers in Figure 2. The circular symbols represent data measured by the FMP (Fluid Mixing Processes) consortium [*5*] using laser-Doppler anemometry and the diamonds represent data measured in the PMSL laboratory using particle-image velocimetry. The data are in agreement showing that measurement technique has no effect on the values of hydraulic efficiency calculated.

The hydrofoils are the most efficient impellers followed by the pitched-blade turbines, then the radial flow flat-blade and Rushton turbines. The high-shear disperser impeller is the least efficient, with a hydraulic efficiency of less than 1%. The difference in efficiency within a class of impellers is a result of the impeller to tank diameter ratio. A larger impeller is more efficient and this definition of hydraulic efficiency does not take this into account.

An alternative definition of efficiency has been proposed by Fort and others [*6*]. This is the mass of fluid pumped per unit of energy input by an impeller:

$$\eta_{HYDR} = \frac{\rho \cdot Q}{P_{MECH}} = \frac{\rho \cdot Fl \cdot N \cdot D^3}{Po \cdot \rho \cdot N^3 \cdot D^5} = \frac{Fl}{Po\left(N \cdot D\right)^2} \quad (12)$$

This quantity has units of kilogram of fluid pumped per Joule of energy input by the impeller.

The power input per unit mass of fluid, for a vessel where depth is equal to vessel diameter, can be calculated from:

$$\bar{\varepsilon} = \frac{Po \cdot \rho \cdot N^3 \cdot D^5}{\left(\pi/4\right) \cdot \rho \cdot T^3} = \frac{4}{\pi} \cdot \frac{Po \cdot N^3 \cdot D^5}{T^3} \quad (13)$$

Re-arranging for impeller speed:

$$N = \left(\frac{\pi \cdot \bar{\varepsilon} \cdot T^3}{4Po \cdot D^5}\right)^{1/3} \quad (14)$$

Substituting Equation (14) into Equation (12) gives the following:

$$\eta_{HYDR} = \frac{Fl}{Po \cdot D^2} \cdot \left(\frac{4}{\pi} \cdot \frac{4Po \cdot D^5}{\bar{\varepsilon} \cdot T^3}\right)^{2/3}$$
$$= 1.175 \frac{Fl}{Po^{2/3}} \cdot \left(\frac{D}{T}\right)^{4/3} \cdot \left(\bar{\varepsilon} \cdot T\right)^{-2/3} \quad (15)$$

The hydraulic efficiency data plotted in Figure 2 are replotted in Figure 3 using the new definition from Equation (15) with a power per mass of 1 W/kg and vessel diameter of 1 m. The effect of impeller diameter is now taken into account and large diameter impellers ($D/T \approx 0.5$) are more efficient than smaller ones ($D/T \approx 0.3$), pumping approximately twice the mass of fluid per unit of energy input.

Shear

In any flowing system, the shear rate is the time-averaged velocity gradient [7].

Oldshue [3] has compared the time-averaged velocity gradients in the discharge of a hydrofoil and pitched-blade and Rushton turbines to show that the Rushton generates higher shear than the pitched-blade, which generates higher shear than the hydrofoil. This has become the conventional wisdom in the mixing field.

Figure 4 shows the mean velocity profiles for a hydrofoil (in green) and pitched-blade turbine (in red), which were measured using particle-image velocimetry in the PMSL laboratory. The dashed lines show the average velocity gradient in the discharge. Figure 5 shows the mean velocity profile for the Rushton turbine and, again, the dashed lines show the average velocity gradient in the discharge. The shear rate is described by the following equation:

$$\dot{\gamma} = \frac{v_H - v_L}{r_H - r_L} \quad (16)$$

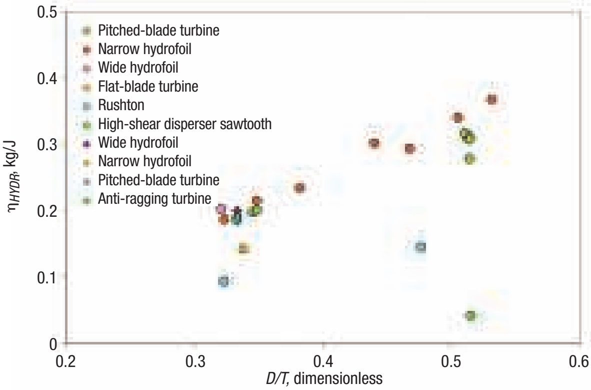

FIGURE 3. Shown here is a plot of the hydraulic efficiency, η_{HYDR}, versus impeller-to-vessel-diameter ratio

where v_H and v_L are the high and low velocities in the gradient and r_H and r_L are the radial positions corresponding to the locations where these velocities were measured. Since the velocities are normalized by the impeller tip speed and the radial positions by the impeller radius, Equation (16) can be re-written as follows:

$$\dot{\gamma} = \frac{(\alpha - \beta) \cdot V_{TIP}}{(\psi - \omega) \cdot R} = \Lambda \cdot \frac{V_{TIP}}{R} \quad (17)$$

Values of α, β, ψ, ω and Λ are given in Table 2. Also the ratio of $\Lambda / \Lambda_{HYDFL}$ is shown and, at equal tip speed and impeller diameter the Rushton generates the highest shear rate followed by the pitched-blade turbine and then the hydrofoil.

Engineers are concerned with the power drawn by the impeller since this determines the size of the agitator needed to achieve the desired process result. Equation (13) can be rearranged to express the power input by the impeller per unit mass of fluid in terms of tip speed:

$$\bar{\varepsilon} = \frac{4}{\pi^4} \cdot Po \cdot \frac{V_{TIP}^3}{T}\left(\frac{D}{T}\right)^2 \quad (18)$$

The π^3 term must be introduced because $V_{TIP} = \pi ND$.

Comparing different impellers of equal diameter at the same scale:

$$V_{TIP} \propto Po^{-1/3} \quad (19)$$

Comparing any impeller with the hydrofoil:

$$\frac{\dot{\gamma}_{IMP}}{\dot{\gamma}_{HYDFL}} = \frac{\Lambda_{IMP}}{\Lambda_{HYDFL}} \cdot \frac{V_{IMP}}{V_{HYDFL}} \quad (20)$$

Substituting Equation (19) into Equation (20):

$$\frac{\dot{\gamma}_{IMP}}{\dot{\gamma}_{HYDFL}} = \frac{\Lambda_{IMP}}{\Lambda_{HYDFL}} \cdot \left(\frac{Po_{HYDFL}}{Po_{IMP}}\right)^{1/3} \quad (21)$$

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TABLE 2: MEAN VELOCITY PROFILE SHEAR RATES

Impeller	α	β	ψ	ω	Λ	Λ/Λ_{HYDFL} at equal V_{TIP}	Λ/Λ_{HYDFL} at equal $\bar{\varepsilon}$
Narrow-blade hydrofoil	0.25	0.14	0.80	0.16	0.17	1.00	1.00
Pitched-blade turbine	0.35	0.07	0.65	0.12	0.53	3.11	1.91
Rushton turbine	0.60	0.16	0.12	0.04	5.50	24.4	9.55

Table 2 also shows the ratio of the shear rates when the impellers operate at equal power input per mass. Taking power numbers from Table 1, the ranking of the impellers does not change. Therefore, whether compared at equal tip speed or power input the Rushton turbine generates the highest shear rate followed by the pitched-blade turbine then the hydrofoil. This ranking can be tested against a process result that is dependent on shear, namely the break-up of droplets to create a liquid-liquid dispersion.

Process result

Mass transfer between two immiscible liquid phases, with or without reaction, is an important process result. The interfacial area available for mass transfer is proportional to the volume fraction of the dispersed phase and inversely proportional to the Sauter mean droplet size [*8*].

If the dispersion is agitated for a long period of time (several hours), an "equilibrium droplet size" is achieved that is stable in the mixing environment in which the droplets are being formed. This means that there is an equilibrium between the forces breaking-up the droplets and the forces resisting break-up resulting from the interfacial tension between the two liquids and the viscosity of the dispersed phase liquid.

Figure 6 shows the Sauter mean droplet size plotted versus the average power input per unit mass for Rushton, two pitched-blade turbines, with blades angled at 45 and 60 deg, a hydrofoil and a high-shear disperser impeller. The experiments were carried out with low viscosity silicone oil as the dispersed phase and at a very low concentration so that the effect of coalescence on the droplet size can be ignored.

If the hydraulic efficiency and shear rate comparison quantify the performance characteristics of the impellers, when compared at the same power input per mass,

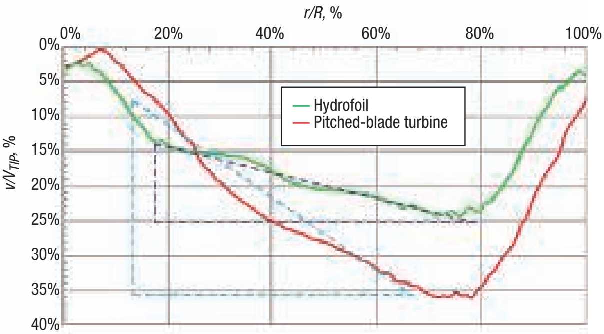

FIGURE 4. This graph shows a plot of the mean velocity profiles for pitched-blade turbine and hydrofoil impellers

the Rushton should create the smallest droplets and the hydrofoil, the largest, with the pitched-blade turbines falling somewhere between these two. In fact, the hydrofoil creates smaller droplets than the Rushton and two pitched-blade turbines and the droplets created by the turbines are indistinguishable experimentally. This result has also been observed by Pacek and others [*9*].

There is another geometrical property of impellers that determines how they create the "fluid dynamic effect" that achieves this desired "process result." This is the trailing vortices that form at the tip of the impeller blades.

Trailing vortex

As the impeller moves through the fluid, the pressure on the leading face of the blade is higher than on the back. The high- and low-pressure zones meet at the tip of the blade and the fluid moves from the high- to low-pressure region creating the trailing vortex. This phenomenon can often be observed on airplane wings [*10, 11*].

In a stirred tank, the velocity and size of the vortices can be measured using laser-Doppler or particle-image velocimetry, then the kinetic energy and energy dissipation rate (the local power input per mass) can be calculated. The kinetic energy of the trailing vortex is often non-dimensionalized by dividing by the impeller tip speed squared. Grenville and others [*12*] have shown that for impellers with blades:

$$\frac{k_{MAX}}{V_{TIP}^2} = 0.104 \cdot Po^{1/2} \qquad (22)$$

Where $V_{TIP} = \pi N \cdot D$.

The standard deviation for this correlation is ±10%.

The maximum energy dissipation rate within the vortex is given by the following equation [*13*]:

$$\varepsilon_{MAX} = A \cdot \frac{k_{MAX}^{3/2}}{l_0} \qquad (23)$$

l_0 is a length scale related to the flow near the impeller and it is a fraction of the impeller diameter. Substituting Equation (22) into Equation (23) and setting $l_0 = D/x$ and $A = 1$:

$$\varepsilon_{MAX} = 1.04 \cdot x \cdot Po^{3/4} \cdot N^3 \cdot D^2 \qquad (24)$$

The standard deviation for this correlation is ±15%.

Where measurements have been made, typical values of x are given in Table 1. Generally, the scale of the trailing vortex for the Rushton and pitched-blade turbines is equal to one-half of the projected height of the blade at its tip. For hydrofoils the scale of the trailing vortex is equal to the projected height of the blade at its tip.

Equations (13) and (24) can be combined to show that the ratio of the maximum energy dissipation rate to the average power input per mass, K, is:

$$K = \frac{\varepsilon_{MAX}}{\bar{\varepsilon}} = \frac{1.04 \cdot x \cdot Po^{3/4} \cdot N^3 \cdot D^2}{Po \cdot N^3 \cdot D^5} \cdot \frac{\pi T^3}{4} = 0.82 \cdot \frac{x}{Po^{1/4}} \cdot \left(\frac{T}{D}\right)^3 \quad (25)$$

The ratio is weakly dependent on the type of impeller (*Po*), dependent on the scale of the vortex (*x*) and strongly dependent on the size of the impeller (*D/T*). The reason for this is that a small-diameter impeller must operate at a higher tip speed than a larger one to input the same power and the maximum kinetic energy is proportional to the tip speed squared.

The droplet size data plotted versus the average power input per mass in Figure 6 are replotted in Figure 7 versus the maximum energy dissipation rate in the trailing vortex. The variations in the trailing vortex energy dissipation rate generated by the impellers and the effects on the droplet size are now correctly accounted for, including the high-shear disperser.

The conventional wisdom in the mixing industry has been that hydrofoil impellers generate "low shear" and Rushton turbines generate "high shear" [*3, 4*] and this is true if only the time-averaged velocity gradients are compared. The maximum kinetic energy dissipation rate within the trailing vortex, ε_{MAX}, generates the stresses that break-up droplets, or any other second phase, in an agitated vessel. Rather than describing these impellers as "high shear," it is more rigorous to call them "high dissipation" or "high stress."

Applications

There are many processes in which the fluid dynamic effect that achieves the process result is commonly considered to be "shear" although, strictly, the process result is determined by the maximum energy dissipation rate within the trailing vortex. One example of a "shear" driven process is flocculation of fine particles. Agitators are designed to provide a desired shear rate, or *G*-value. *G* is defined as:

$$G = \left(\frac{P}{\mu \cdot V}\right)^{1/2} = \left(\frac{Po \cdot \rho \cdot N^3 \cdot D^5}{\mu \cdot V}\right)^{1/2} \quad (26)$$

This shear rate is based on the vessel-averaged power input per volume and the fluid's dynamic viscosity. Equation (26) suggests that, provided that the average power per volume is kept constant, the same *G*-value will be generated and the flocculation performance will be the same. Benz [*14*] has written a review of the problems that will be encountered taking this approach to agitator design, especially the fact that it takes no account of impeller type or diameter. He concludes that "*G*-value has no legitimate use in designing or specifying agitators."

Spicer and others [*15*] have measured the size and structure of flocculated polystyrene particles using a hydrofoil, pitched blade and Rushton turbines at G-values, as defined in Equation (26), of 15, 25 and 50 s^{-1}. The corresponding values of vessel-averaged power input per mass are 2.25 × 10^{-4}, 6.25 × 10^{-4} and 2.50 × 10^{-3} W/kg. Grenville and Spicer [*16*] have re-analyzed these data and the floc length versus the maximum kinetic energy dissipation rate, calculated using Equation (23), is plotted in Figure 8. This approach to the analysis correlates the data and suggests that the concept of a *G*-value should work for agitator design provided that it is based on the maximum energy-dissipation rate in the trailing vortex — not the vessel averaged power per volume.

The selectivity of competitive reactions carried out in semi-batch mode is determined by the local mixing rate [*17*], the micro-mixing rate, in the region where the added reactant is introduced to the vessel [*18*]. Bourne and Dell'ava [*19*] have shown that the selectivity of an azo-coupling reaction can be maximized by feeding the added reactant at the impeller where the trailing-vortex energy dissipation rate determines the rate of micro-mixing. They, and Nienow and others [*20*], have also shown that, provided the feed location is geometrically similar, the selectivity of the reaction can be maintained on scaleup if the trailing-vortex energy dissipation rate is the same at the two scales. This has also been shown to apply to precipitation reactions where the particle size and morphology need to be controlled [*21, 22*].

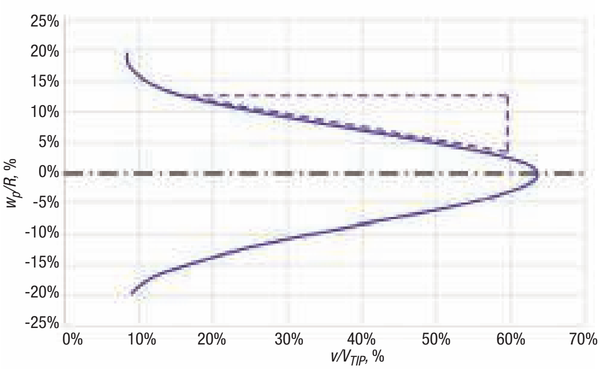

FIGURE 5. This graph shows a plot of the mean velocity profiles for the Rushton turbine

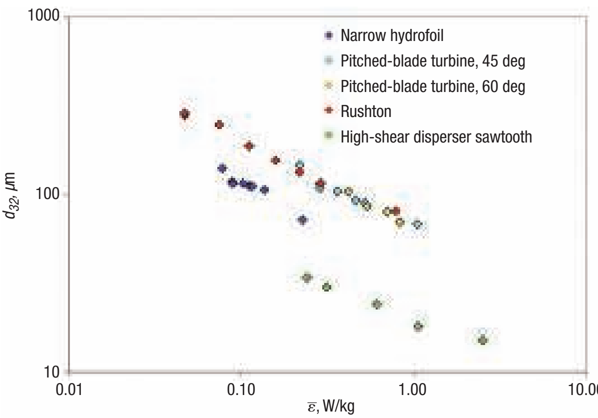

FIGURE 6. This graph shows the behavior of the Sauter mean diameter, d_{32}, versus vessel-averaged power input per unit mass

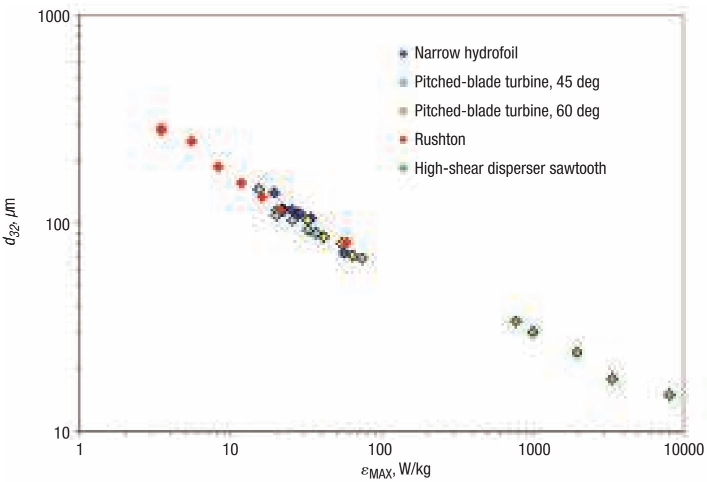

FIGURE 7. Shown here is a plot of the Sauter mean diameter, d_{32}, versus the trailing vortex energy-dissipation rate

Finally, mixing in crystallization processes requires both rapid local mixing to minimize primary nucleation and high flow to promote homogeneity, favoring secondary nucleation and crystal growth. Also, a balance between crystal growth and crystal damage must be considered in choosing the appropriate impeller [*23*].

Conclusions

Mixing processes can be described in terms of the desired process result. Generally this result will be controlled by the flow and turbulence intensity generated by an impeller. The approach described here can be used to determine which the best impeller to achieve this result will be. It can also be used to translate laboratory and pilot-scale results taken with one type of impeller to a larger scale using a different geometry, provided that the process result and controlling dynamic effect can be identified.

The term high-shear is commonly used to describe an impeller's capability for dispersion of a second immiscible phase generating surface area for mass transfer. Similarly, low-shear is used to describe impellers that, in multi-phase processes, allow the second phase to grow, and flocculation is a good example of this.

In a turbulent agitated vessel, the time-averaged velocity gradients are of little use, and potentially misleading, for comparison of impeller performance and agitator design. While the term "shear" is used qualitatively to describe impellers' dispersing capabilities, it must be recognized that the true mechanism of break-up is determined by the maximum energy dissipation rate within the impellers' trailing vortices. This understanding enables engineers to select the appropriate impellers for their processes. ■

Edited by Gerald Ondrey

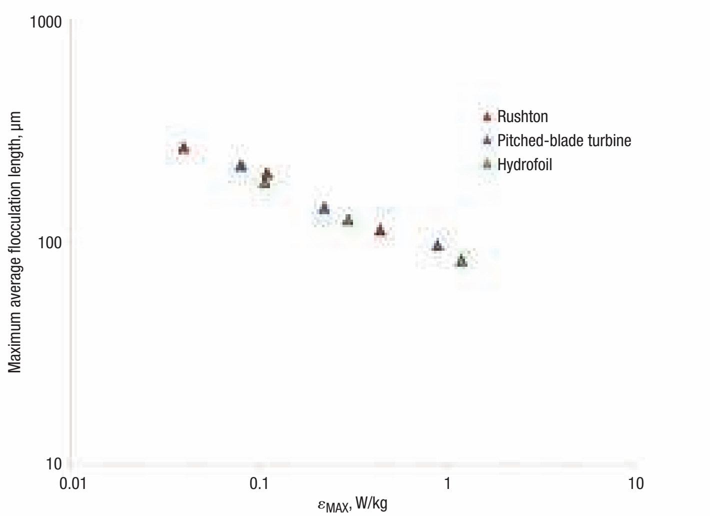

FIGURE 8. This plot shows the maximum average floc length versus maximum kinetic-energy-dissipation rate for hydrofoil, pitched blade and Rushton turbines

References

1. Etchells III, A. W., Lecture notes, CHEG 615 Special Topics in Mixing, University of Delaware.
2. Machado, M. B. and Kresta, S. M., "Advances in Industrial Mixing," ch. 2b, pp. 47–84. John Wiley and Sons, New York, N.Y., 2016.
3. Oldshue, J. Y., "Fluid Mixing Technology," McGraw Hill, New York, N.Y., 1983.
4. Ducoste, J. J., Clark, M.M. and Weetman, R. J., Turbulence in Flocculators: Effects of Tank Size and Impeller Type," *AIChE J.*, 43 (2), pp. 328–338, 1997.
5. Brown, D. A. R., Mixer Performance Characteristics: Impeller and Process Efficiency", presented at Mixing XXII, Victoria, B.C., Canada, 2010.
6. Fort, I., B. Kysela, B. and Jirout, T., Flow Characteristics of Axial High Speed Impellers," *Chem. Proc. Eng.*, 31, pp. 661–679, 2010.
7. Pnueli, D. and Gutfinger, C., "Fluid Mechanics," ch. 1, p. 11, Cambridge University Press, Cambridge, U.K., 1992.
8. Russell, T. W. F., Robinson, A.S. and Wagner, N.J., "Mass and Heat Transfer," ch. 7, p. 302, Cambridge University Press, Cambridge, U.K., 2008.
9. Pacek A.W.,Chamsart, S., Nienow, A.W. and Bakker, A., The Influence of Impeller Type on Mean Drop Size and Drop Size Distribution in an Agitated Vessel", *Chem. Eng. Sci.*, 54, pp. 4211–4222, 1999.
10. www.youtube.com/watch?v=ViKYFsN3p24.
11. www.youtube.com/watch?v=zW4PmUE151c.
12. Grenville, R. K., and others, "Flow and Shear in Agitated Vessels," presented at AIChE Annual Meeting, Philadelphia, Pa., 2008.
13. Tennekes, H. and Lumley, J. L., "A First Course in Turbulence," ch. 3, p. 68, MIT Press, 1972.
14. Benz, G. T., "The G-value for Agitator Design: Time to Retire it?", *Chem. Eng. Prog.*, pp. 43–47, March 2007.
15. Spicer, P. T., Keller, W. and Pratsinis, S. E., "The Effect of Impeller Type on Floc Size and Structure During Shear-induced Flocculation," *J. Colloid Interface Sci.*, 184, pp. 112–122, 1996.
16. Grenville, R. K. and Spicer, P.T., "Mixing and Flocculation of Fine Particles," presented at Mixing XXV, Quebec City, Que., Canada, 2016.
17. Paul, E. L. and Treybal, R.E., "Mixing and Product Distribution for a Liquid-phase, Second-order Competitive-consecutive Reaction", *AIChE J.*, 17, pp. 718–724, 1971.
18. Bałdyga, J. and Pohorecki, R., "Turbulent Micromixing in Chemical Reactors — A Review," *Chem. Eng. J.*, 59, pp. 183–195, 1995.

19. Bourne, J. R. and Dell'ava, P., "Micro- and Macro-mixing in Stirred Tank Reactors of Different Sizes", *Chem. Eng. Res. Des.*, 65, pp. 180–186, 1987.

20. Nienow, A. W., Drain, S.M., Boyes, A. P. and Carpenter, K. J., "An Experimental Study to Characterize Imperfect Macromixing in a Stirred Semibatch Reactor," *Ind. Eng. Chem. Res.*, 36, pp. 2,984–2,989, 1997.

21. Phillips. R., Rohani, S. and Bałdyga, J., "Micromixing in a Single-feed Semi-batch Precipitation Process", *AIChE J.*, 45, pp. 82–92, 1999.

22. Vicum, L. and Mazzotti, M., "Multi-scale Modeling of a Mixing-precipitation Process in a Semi-batch Stirred Tank," *Chem. Eng. Sci.*, 62, pp. 3,513–3,527, 2007.

23. Tung, H-H, Paul, E. L., Midler, M. and McCauley, J. A. "Crystallization of Organic Compounds: An Industrial Perspective," ch. 6, John Wiley and Sons, New York, N.Y., 2009.

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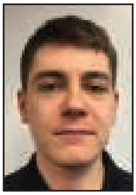

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Control Room Design for Chemical Engineers

Chemical engineers bring many essential skills to the diverse teams required for successful control room design

Brad Adams Walker
Peggy Hewitt
BAW Architecture

BAW Architecture

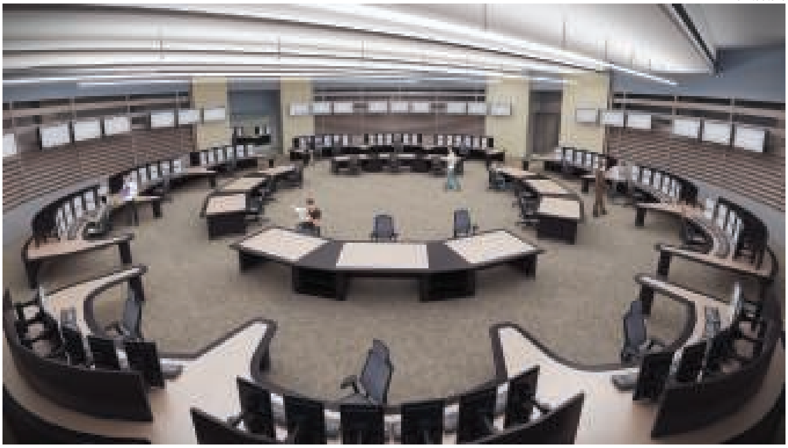

FIGURE 1. Many of a plant's most critical operational tasks take place in a control room. A thoughtfully designed control room will enable collaboration, safe operations and ergonomic working conditions

In any continuous manufacturing plant in the chemical process industries (CPI), engineers need to consider control room architecture and design as part of their responsibility. Chemical engineers may think that this is not their area of expertise, and therefore not their responsibility. This is understandable, but this article explains why engineers should spend time thinking about control room architecture.

Chemical engineers spend their careers making the world a better place. They may develop new products and materials, manufacture existing products, recycle waste or clean the environment and create energy. Design and architecture are not typically their strong suits, and indeed they may not have given much time to understanding the configurations that make a control room safe, efficient and productive. However, architecture and design have a profound effect on how one executes the demands of his or her profession.

The reality is that it takes more than four walls and some fancy desks to design a control room that will last a generation, be an environment where operators can safely manage the chemical processes and where teams of people can collaborate to solve problems quickly and keep the plant running efficiently (Figure 1).

That's not to say chemical engineers need to come up with all the answers — there are architectural firms that specialize solely in control room design of the highest caliber — but there are a number of reasons why knowing how to ask the right questions is in chemical engineers' best interest.

The operator

Demographics are such, particularly in North America, that plants are losing the most experienced operators to retirement faster than new personnel can be hired and trained — the latest generation of workers seem to have different aspirations and motivations for their careers. In the last 30 years, we we have greatly improved understanding of how operators worked and reacted to situations, but that experience and research applies mainly to an older generation. We simply do not know enough about what will change with a younger generation of operators. For this reason alone, when planning how the process will be controlled, it is essential to ensure that the room is designed from the operator outward. You should be asking: "What environment will ensure that the operator is comfortable, has a high situational awareness and is empowered to make the decisions necessary to operate a safe plant?"

A best practice often used is a charrette (Figure 2). A charrette is a workshop-style meeting that is used to gather structured information from operators and other stakeholders from which the building blocks of the new facility take shape. The goal is to achieve consensus by the end of the three-day process on a block plan direction. Integration of best practices in control room design is woven throughout the approach. Human factors engineering (HFE) is an integral part of the control room charrette, and the data gathered during this phase informs the control room layout, control system and console design.

The operator is key to the successful design of a control room (Figure 3). His or her input is invaluable throughout the entire design process. Beginning in front-end engineering design (FEED), the operator should be engaged in design charrettes all the way through 100% design completion, and consulted for such items as workstation design, screen graphics and the human machine interface (HMI). Understanding the operators' needs — mainly, how they interface with complex systems within a high-pressure environment — is "square one," and all other design decisions flow out from that pivotal point. The most successful control buildings have been designed with the operators involved as part of the team from the project commencement.

Collaboration

No matter how strongly individuals excel in chemical engineering, no organization can survive without collaboration. One of the key insights to harnessing collaboration is diversity. Experiments have shown that groups composed of only highly adept members are outperformed by groups with members of varying skill levels and knowledge [*1*].

While having a team made up of a number of brilliant engineers seems desirable, encouraging a diversity of perspective will help ensure an optimal outcome as you plan for a new control room or a control room renovation. To that end, it is recommended that input be solicited from not only chemical engineers, but also from automation engineers, control engineers, human factors specialists, designers, architects and, of course, operators.

As part of this collaboration, one best practice is allowing sufficient time in the FEED phase to adequately plan and design a control room by integrating human factors engineering and the ISO 11064 standard, which spells out international standards in control room design [*2*]. This ensures that before the project gets too far down the road, risks and tasks are analyzed, and adjacencies and future expansion needs are identified. Drawings are produced and revised until consensus is reached (Figure 4). To have upper management commitment — and better yet, an HFE champion and liaison from the company on board to work with the team from the beginning and throughout all phases of the project — offers the most successful approach to control room design.

Involving HFE early in the FEED stage to provide expertise at the beginning lays a solid foundation for the development of the successful design. Involving a diverse collaboration team in decision-making throughout the process makes for a stronger design solution and allows for their early buy-in. Designing the work environment ergonomically to suit the operator is proven to reduce human error, accidents and illness, and designing it correctly the first time by utilizing the expertise of an HFE and control-room architect can save costly redesign efforts after the building is up and running. The 1:10:100 rule of thumb is often used when engineers are evaluating product quality. Through experience and case studies, we can also apply this to control room design. In short, if it costs $1 to fix a usability problem during design, it will cost $10 to fix once the system is developed, and $100 to fix once it is operational.

ISO 11064 recommends an iterative review process for the design of control buildings involving operators and engineers that will be working in the control room in meetings and decision-making. It leads the design work toward the best possible solution, and will create buy-in and a sense of owner-

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FIGURE 2. A charrette meeting is useful in planning control room projects in that many different stakeholders with diverse backgrounds can contribute their input and reach consensus on important goals

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FIGURE 3. Seeking operators' input is extremely valuable throughout all phases of control room design

ship in the design.

In these meetings, participants need to identify risks associated with design. Some examples of these risks are the following:

- The control room is not designed to current ergonomic standards
- The design does not include enough area for potential future expansions
- If the building is in a remote location, not having skilled workers to provide construction labor
- Poor onsite security
- Poor communication because of multi-cultural teams

Effectively collaborating when planning a new control room will help on many fronts. The key aspect of having a diverse team (including chemical engineers) planning, reviewing and iterating on the design of the control room will ensure that the final product is one that everyone can agree on, and that optimizes the safety, situational awareness, job satisfaction and productivity of the site.

Change management

Organizations are often good at managing technical change. Chemical engineers must follow very specific change-management procedures when making any changes to manufacturing processes. Why do we put so much effort into this area? It's simple: change-management systems and processes help to ensure that process and technical changes are risk-assessed so that fewer unforeseen consequences occur.

Organizations often do not apply the same level of change-management scrutiny to organizational changes. Implementing a new control room or control room renovation may involve some technical change, but we need to remember that the organizational change elements can be far greater for the employees. As such, the organizational change also must receive comprehensive planning, risk-assessment and management through the transition to make sure to reduce the risks related to major accidents. The key success factors for managing organizational change are as follows:

- Effective planning for the organizational changes
- Communicating with and involving key site personnel
- Assessing the risks relating to the change, including both risks from the process of change and risks from the outcome of the change
- Introducing and monitoring the change as it transitions

Furthermore, specific change-management preparation for staff includes the following:

- Providing upfront technical training to prepare for new systems
- Selecting and nurturing a highly respected project team
- Preparing leaders to lead the change in their areas and to collaborate across enterprises and departments
- Following a disciplined change process

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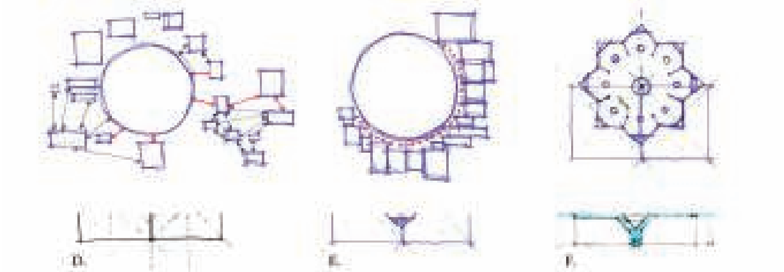

FIGURE 4. Allowing sufficient time for front-end design work, including conceptual sketches and human factors engineering, can save time and reduce costs as the control room project progesses

- Sustaining new positive behaviors after implementation

Chemical engineers certainly understand the importance of solid change management, and their experience is essential to help support the organizational change management that is necessary for planning and adapting to a new control room or renovation.

Steps to success

Following a set methodology, each control room design process — for both new construction and renovations of existing facilities — can deliver exceptional and tangible results. When a project need is identified, a design team is formed. The makeup of that team can facilitate the project process. An experienced control-room design team integrates lessons learned and best practice knowledge for the new facility. The design is fine-tuned throughout the design process based on feedback from many parties. As a result, the control room will have received input from operators, staff and key project stakeholders, often including chemical engineers, and is a multi-disciplinary collaborative creation.

Build a great design team. The motivation to design or renovate a control room usually begins with operations, but is mostly decided by company leadership. Engaging an experienced architectural team consisting of architects, engineers, human-factors engineers and interior designers is an integral first step in the process. Understanding the value that a new or renovated control room can bring to an organization involves a comprehensive approach. The roles and responsibilities of each discipline, described below, are a vital piece to a complex puzzle:

- Architect: oversees the overarching concept and the design team (including structural, mechanical and electrical considerations, among others) and keeps the project on course
- Human factors engineer (HFE): ensures a human-centered approach based on ISO-11064 and industry best practices
- Interior designer: integrates all the disciplines together into an operator-centric, ergonomic and functional environment

Hiring experts in the design of control buildings ensures the building will be designed correctly the first time, reducing human error, avoiding costly renovations, accidents and illness related to poor design. Together, the team of specialists works collaboratively to design a control building that meets the needs of the operator. Lastly, an experienced building contractor can make or break the project by providing cost and schedule control to keep the project on budget and on time, as well as risk mitigation so that the job site stays safe. Collaborating with the owner and architect, the contractor turns the team's vision into a reality.

So the next time there is talk of designing a new control room or renovating an existing control room at your organization, remember the reasons why you should get involved — the operator, collaboration and change management. What these three areas have in common is the need for a cross-functional approach to job design, work design and planning and implementation, all focused on improving process safety, efficiency and productivity.

Some additional lessons learned from the authors' extensive experience in designing and building control rooms and buildings include the following:

- Allow enough time in FEED to start a control room project off right
- Workstations, as well as small and large screen placement, should be designed concurrently with the building design
- Incorporate area for future growth in the control room, rack room and infrastructure
- Communication and collaboration across the design team and with operational staff (including chemical engineering) and the construction team is key to successful organizational change and control room design. ■

Edited by Mary Page Bailey

References

1. Goman, Carol K., Seven Insights for Collaboration in the Workplace, *Reliable Plant*, April 2010.
2. International Organization for Standardization (ISO) 11064, Ergonomic Design of Control Centres, November 2013.

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Outsourcing and Offshoring Engineering and Fabrication Activities

Follow these tips to get the most out of these high-risk, high-reward, third-party arrangements

Carl Rentschler
Engineering Consultant
Goutam Shahani
ShureLine Construction

Outsourcing is the subcontracting of a business function to an outside entity. The concept of outsourcing was first articulated by David Ricardo, an English economist in the 19th century. The idea is that through the use of outsourcing, companies can concentrate on those activities where they bring the greatest value. Lower-value activities are then carried out by other parties so that a company can focus its efforts and resources on its core competencies, and thereby achieve a comparative advantage in the marketplace.

This principle of outsourcing is widely applied in our personal and business lives. We routinely hire outside plumbers and electricians even if we are able to carry out these activities ourselves, so that we can spend our time on higher-value endeavors and still have time for recreation. In most corporations, such functions as landscaping, cafeteria services and security, among others, are typically subcontracted out. This provides flexibility, frees up capital and allows for lower overhead.

The maturing chemical process industries (CPI) have been undergoing drastic changes in the last three decades. Innovation was the primary growth driver in the earlier stages. However, companies are increasingly seeking opportunities to realize further cost savings and efficiency gains for further growth. In addition, competitive market factors demand faster schedules and flexibility. In the not-too-distant past, many large chemical-manufacturing and petroleum-refining corporations maintained their own fully staffed engineering and construction offices. However, more recently, many of these functions have been hollowed out and these days, many CPI companies now routinely rely on outside firms to carry out these functions more efficiently.

The terms outsourcing and offshoring are related. Offshoring is similar to outsourcing. However, it entails sending work outside the home country. While outsourcing can be done within the national boundaries, offshoring refers to getting work done outside of the country. Offshoring is typically done to take advantage of lower labor and material costs, and often carries potential currency-exchange risks — both positive and negative. Offshoring also has implications to domestic jobs and tends to be a more politically charged issue.

Descon

FIGURE 1. This photo shows a fluegas-conditioning module, which is part of a large process plant that was fully fabricated in a local shop in the Middle East to achieve the desired schedule

Pros and cons

The primary driver for considering outsourcing is cost savings. In today's very competitive market, every effort must be made to save costs where possible. The cost savings can come in various forms as follows:

- Lower per-hour engineering costs
- Lower fabrication costs, even after potentially adding more shipping costs
- Development of construction modules to lower field construction costs

Care should be taken to ensure that outsource economic decisions are made with eyes wide open. What may appear to be huge savings may not always be the case. For example, if overseas engineering is used at a rate that is reduced by 50% per hour (compared to home-office rates), but then requires two times the number of hours to be used,

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there is no benefit.

Similarly, with overseas fabrication, care must be taken to ensure that shipping costs do not consume fabrication savings. It is also important to take into account customs duty for importing equipment through an outsourcing arrangement.

Schedule-related considerations may also be a significant driver for outsourcing. Perhaps there are insufficient resources within the company for the project to be executed, and the only way to meet schedule is through the use of external resources. Splitting up work among different entities may create inefficiencies, yet this may be the only alternative to achieve contract schedule requirements.

Different approaches

When considering outsourcing either domestically or internationally, there are various options to consider in deciding how to proceed. The common drivers for pursuing an outsourcing arrangement are the scope of the work, the level of internal resources to manage the work, and the desired outcome.

Care should be taken to make all outsourcing decisions with eyes wide open. Apparent or anticipated savings or operational advantages may not always come to fruition

If the scope includes significant engineering, there may be more of an impetus to establish a local presence in the foreign country outsource location. If the scope involves strictly fabrication by a foreign company, it may be prudent to work through a U.S. agent of the fabricator, or to utilize your own purchasing or procurement department to deal with the fabricator (this will be more of an "arms-length" arrangement).

When internal resources are limited and the desired goal is a long-term relationship, it may be wise to consider an alliance or partnership. Gaining specific technology may be another reason for considering a more formalized outsourcing structure. All facets of the outsourcing goals should be evaluated to determine the best path forward. The most commonly used outsourcing arrangements are described below.

Outsourcing through the procurement function. In its simplest form, outsourcing can be accomplished through the normal procurement process. In this manner the technical personnel develop a specification, while procurement personnel issue a request for quotation (RFQ) to qualified bidders. This method of outsourcing provides the lowest amount of control and often is not intended to establish a long-term relationship. This method tends to be very price competitive but perhaps with less focus on quality and workmanship. Often, quality audits are relied upon to ensure that quality is maintained through the engineering or fabrication processes, and there is little or no ongoing work surveillance.

Hire an agent who represents the service company. A somewhat informal or unstructured approach to outsourcing is to utilize an agent who represents the service company. This is a far more economical approach than establishing a local presence in an outsource location, and is more frequently considered for equipment or component fabrication than for large engineering projects.

Such an agent provides the service provider with local sales capability in the U.S. in a very cost-effective manner. Not only can the agent represent multiple clients with non-competing interests, but the agent will typically understand local customs and business practices, and reside in the same time zone. For example, if services are provided in the U.S. by a foreign company, the local agent will serve as an intermediary for the foreign company. Essentially, such an agent will function as the local eyes and ears for the foreign company.

For the buyer, the agent provides local knowledge of the provider's offerings and can serve as a resource for answering questions. The agent is often counted on to be the front line with any warranty issues. The key for this outsourcing method to be effective is to have a sales agent who is fully knowledgeable in the services, and someone who is very well connected in the industry.

Form alliances with other companies. When a long-term relationship is of interest, an alliance between two or more companies is often considered as a means of outsourcing. This is often considered when one company needs a technology, and another company offers this technology. One well-known alliance exists in the hydrogen production area, in which Air Products (www.airproducts.com) has a long-term alliance with Technip (www.technip.com) for reformer technology. Often a pricing agreement is part of the alliance as a tradeoff for the provider being the exclusive source of the equipment or engineering. The downside is that price competitiveness may come into question over time with no competitive price checks are being made.

Create partnerships. A partnership may be considered as a means of outsourcing in cases when two companies offer complementary services, and together as a team they provide greater opportunity. For example, if a company is strong in EP (engineering – procurement) due to their technology strengths, but weak in C (construction), they may want to choose a partner that would improve their chances of winning large EPC projects. This is the very scenario that developed between Linde (www.linde.com) and Bechtel (www.bechtel.com) in the ethylene market. The partnership has been fruitful in winning and executing, among other things, the large Baytown ExxonMobil plant expansion project. Under the partnership arrangement, both parties have a contract with the owner, which often manages both companies. The owner is able to get the best of all elements of the project, although there is generally a cost premium under this arrangement.

Establish a local office. Establishing an office in the outsource location is a widely used method to gain access to lower-cost engineering services in foreign countries. By way of example, countless companies have established offices in locations such as India and China. Establishing these offices takes time and involves key personnel from the parent company to drive the process at the location. Once key employees are hired, the next step is to indoctrinate the outsource location into the way of doing business in your company. This may involve sending key hires to the home office for extended training, and may even involve home-office technical personnel spending periods of time at the outsource location to ensure proper indoctrination and implementation of standards.

Once the remote office has been established, new challenges present themselves. Trained personnel in a foreign country become a sought-after talent. Special efforts are often necessary to retain key personnel.

And, once that local resource has been established, keeping the group busy becomes an important ongoing objective. This requires workload balancing that can affect the home office. The home office has to also remember that it accepts full responsibility for the work in the outsource location, and cannot point fingers when problems arise. The phrase "we" instead of "they" must be the practiced team terminology. Additional challenges that are often associated with this type of arrangement include: communication across different time zones and languages.

Additional challenges

Some specific challenges were pointed out above with each outsourcing method, but there are also some generic concerns that exist with offshoring and outsourcing. These can generally be overcome, yet special thought and consideration should be given as such arrangements are pursued.

Most worldwide engineering companies and fabricators have a working knowledge and certification with U.S. codes. Foreign companies have to educate themselves to U.S. code requirements. This adds to their cost and erodes some of their lower cost advantage. In instances where U.S. companies build projects for eventual deployment overseas, the company that delivers the outsourced engineering and fabrication has to have a thorough knowledge of the codes in the country where the equipment will be eventually deployed.

There are situations where local codes become involved as U.S. companies do work worldwide. These countries' codes may not be familiar to the engineering company or fabricator and can require a learning process. For example, if a U.S. company is developing a project in Korea, the Korean Gas Safety Code (KGSC) must be followed. When outsourcing work to a country that has lower labor and material costs (such as India or China), care must be taken to ensure that the provider is capable of working to the relevant code.

The time zone difference may also become an inconvenience when outsourcing to foreign companies. Very often, a parent company in the U.S. or Europe arranges meetings and teleconferences during regular working hours in the local time zone. This may correspond to the evening and late night for people who live in Asia.

For most routine interfaces, it is possible to address communications via emails and scheduled conference calls. However, the challenge arises when urgent problems occur and a quick response is needed from the outsource location. During crucial times of a project, this can be handled by requiring that the outsource location stagger their work schedule to ensure full coverage during the working hours of the parent company's office. Some companies will make whatever accommodations are necessary to facilitate communication with a foreign company. This includes maintaining staff after hours for conference calls and other communications.

Finally, language and cultural differences may come to bear when outsourcing to foreign locations. U.S. companies enjoy the advantage that technical and business professionals in most other countries speak some English with some proficiency, yet there can still be strained communications. The experience of the authors is that personal interface is the best way to avoid confusion. This can be achieved by having someone at the outsource location, or by dealing regularly through a representative.

In addition, there may be cultural differences. For instance, in some countries, young engineers are comfortable completing all defined tasks with a lot of direct supervision. However, they are not trained to work independently or be proactive.

Closing thoughts

Outsourcing and offshoring are well-known techniques to reduce cost, improve schedule, balance workload and improve flexibility. Outsourcing can be carried out at different degrees, ranging from using the existing procurement function or hiring an agent, to forming an alliance, partnering with others or establishing on offshore office. Each approach has its own pros and cons and the appropriate arrangement must be chosen based on the scope of work, internal resources and desired cost savings. Considerations related to schedule, quality, labor productivity and control must be also examined. Finally, costs associated with freight, custom duty and currency-exchange rates have to be taken into account. The best arrangement will be dependent on the specific circumstances associated with a given project or initiative. ■

Edited by Suzanne Shelley

References

1. S. Shahani, G. Shahani, M. Crisler, L. Kogan, Project management: Construction of modern-day hydrogen capacity in the Middle East, *Hydrocarbon Processing,* February 2014.
2. C. Rampell, Outsource Your Way to Success, *New York Times,* November 5, 2013.

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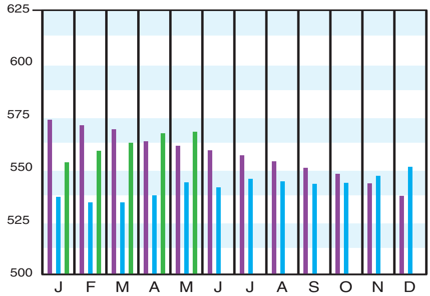
CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957-59 = 100)	May '17 Prelim.	Apr. '17 Final	May '16 Final
CE Index	567.3	566.6	543.5
Equipment	684.5	684.2	649.3
Heat exchangers & tanks	603.5	600.8	560.5
Process machinery	681.0	673.0	650.5
Pipe, valves & fittings	873.5	885.0	813.0
Process instruments	403.6	404.2	385.1
Pumps & compressors	979.6	978.6	970.4
Electrical equipment	516.4	515.5	508.7
Structural supports & misc.	737.1	735.7	719.1
Construction labor	325.9	324.0	325.9
Buildings	559.6	556.5	543.5
Engineering & supervision	314.0	314.2	315.6

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

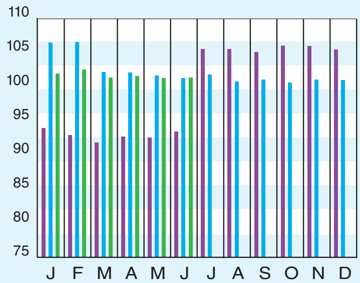
Annual Index:
2009 = 521.9
2010 = 550.8
2011 = 585.7
2012 = 584.6
2013 = 567.3
2014 = 576.1
2015 = 556.8
2016 = 541.7



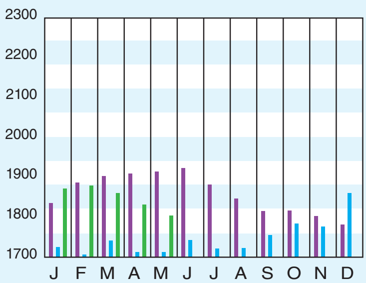
CURRENT BUSINESS INDICATORS

	LATEST	PREVIOUS		YEAR AGO
CPI output index (2012 = 100)	Jun. '17 = 101.3	May '17 = 100.8	Apr. '17 = 100.9	Jun. '16 = 99.9
CPI value of output, $ billions	May '17 = 1,804.1	Apr. '17 = 1,826.6	Mar. '17 = 1,830.1	May '16 = 1,693.5
CPI operating rate, %	Jun. '17 = 76.0	May '17 = 75.7	Apr. '17 = 75.7	Jun. '16 = 75.5
Producer prices, industrial chemicals (1982 = 100)	Jun. '17 = 251.3	May '17 = 257.3	Apr. '17 = 256.5	Jun. '16 = 227.0
Industrial Production in Manufacturing (2012=100)*	Jun. '17 = 103.3	May '17 = 103.1	Apr. '17 = 103.5	Jun. '16 = 102.1
Hourly earnings index, chemical & allied products (1992 = 100)	Jun. '17 = 174.9	May '17 = 174.7	Apr. '17 = 177.5	Jun. '16 = 166.6
Productivity index, chemicals & allied products (1992 = 100)	Jun. '17 = 101.9	May '17 = 102.1	Apr. '17 = 101.0	Jun. '16 = 101.4

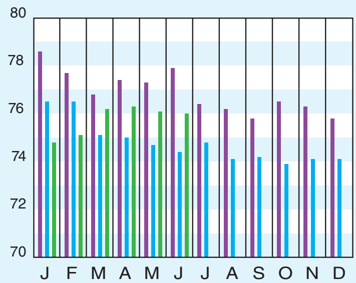
CPI OUTPUT INDEX (2000 = 100)†



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 May *CE* Plant Cost Index (CEPCI; top; most recent available) rose compared to the previous month's value, making it the eighth straight month of increasing values. New data for carbon-steel plates pushed the Equipment subindex higher, while gains were also observed in the Construction Labor and Buildings subindices. The Engineering & Supervision subindex fell by a small margin. The preliminary overall monthly CEPCI value for May 2017 stands at 4.4% higher than the corresponding value from May 2016. Meanwhile, the latest Current Business Indicators (CBI; middle) saw the CPI Output Index for June edge upward slightly. The CPI Value of Output for May fell compared to the April number.

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